The Effect of Blue-Light-Blocking Amber Glasses on Sleep & Affect

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Abstract

Sleep disturbance and mood dysregulation are widely-experienced and costly concerns, even at the sub-clinical level. Sleep disturbance and mood dysregulation are mechanistically and diagnostically linked through circadian rhythms. Blue light has strong influence on entraining circadian rhythms, and controlling blue light has become a target of many interventions aiming to improve sleep and mood. The use of amber lenses, which selectively block blue wavelengths of light, are one such intervention. Past studies have found that amber glasses can be a helpful adjunct treatment for some severe mental illness (e.g., bipolar disorder), but research has been inconclusive about how amber glasses affect people with sub-clinical sleep and mood concerns. Using a randomized crossover design with a wide variety of objective and self-report measures, the present study examined the effect of blue-blocking amber glasses on sleep quality, latency, efficiency, and duration, as well as positive and negative affect in 15 participants over a 14-day period. Overall, our results did not support our hypothesis that amber glasses would increase sleep quality, duration, and efficiency, and decrease sleep latency, although minor but non-significant positive changes were observed on some sleep outcome variables. Our results did, however, provide strong preliminary evidence that amber glasses enhance positive mood at night, and some evidence that amber glasses decrease negative mood in the morning. This study was limited by a small sample size, large interpersonal variation, and some participant noncompliance. Future studies should work to address these limitations, as well as solve extant methodological and analytical problems surrounding objective measures of sleep.

The Effect of Blue-Light-Blocking Amber Glasses on Sleep and Affect

Sleep dysregulation plays a transdiagnostic role in a wide range of physical health outcomes—cancer (Blask, 2009), obesity (Garaulet & Madrid, 2010), heart disease (Stevens et al., 2013), illness or injury recovery (Zelinski et al., 2014), and jet lag (Brown et al., 2009)—and mental health outcomes—depression (Esaki et al., 2016; Salva & Hartley, 2012), bipolar disorder (Henriksen et al., 2016; van der Lely et al., 2015), suicide (Bernert & Joiner, 2007), memory (Zelinski et al., 2014), energy (Franke et al., 2009), and alertness (Sasseville et al., 2015). Sleep dysregulation is linked to mental health outcomes through biochemical pathways that regulate circadian rhythm (Salva & Hartley, 2012). Given the strong linkages between mental health outcomes, sleep, and circadian rhythm, low-cost sleep hygiene interventions have been developed to improve sleep duration, rhythmicity, and quality, as well as mood and cognition. One such intervention—light manipulation—controls ambient blue light, which is a stimulus for the biochemical pathways that entrain circadian rhythm (Salva & Hartley, 2012). Some light manipulation interventions increase participant exposure to blue light during the day, which has been shown to improve mood and alertness (Sasseville et al., 2015; Szabó et al., 2004). However, the light manipulation intervention examined in this paper uses blue-light-blocking amber lenses to lessen exposure to blue light before bedtime (Kimberly & James R., 2009). The introduction describes the biological mechanisms that link blue light to the different health outcomes of interest, outlines the results of previous research that examined light manipulation across the health outcomes of interest, and delineates the aims and contributions of the present study to the light intervention literature.

How Blue Light Affects Sleep

Blue light modulates many circadian rhythms within the body through a retinal pathway that connects to the body's master clock. In most organisms, a biological clock is present that controls bodily processes with circadian rhythmicity (Salva & Hartley, 2012; Wirz-Justice, 2009). A circadian rhythm is the endogenous, continuous 24-hour oscillation of any physiological variable (Guido et al., 2010; Wirz-Justice, 2007). The sleep/wake cycle is one such circadian rhythm, but body temperature and many hormones also oscillate on a 24-hour cycle, and are therefore also circadian rhythms (Guido et al., 2010; Wirz-Justice, 2007). The suprachiasmatic nucleus (SCN), which is located in the anterior hypothalamus, maintains intrinsic circadian rhythms in humans and is therefore referred to as the master circadian clock (Guido et al., 2010). The SCN controls circadian rhythms through both the oscillating activation and deactivation of specific clock genes, and through activation of the pineal gland, which controls the rhythmic production of melatonin (Vela-Bueno et al., 2007; Wirz-Justice, 2009). Melatonin is a neurohormone that has several functions related to reinforcing and stabilizing circadian rhythms, including the sleep/wake cycle (Vela-Bueno et al., 2007; Wirz-Justice, 2009).

This system functions endogenously without the need of external stimuli; however, external stimuli regulate and reset daily circadian rhythms. The SCN, though it maintains a free-running 24-hour rhythm without external stimuli, it is entrained and reset daily by external *zeitgebers* ("time givers")(Asarnow et al., 2014; Macchi & Bruce, 2004; Wirz-Justice, 2009). Because circadian rhythms evolved corresponding to day and night patterns, light is a particularly strong external zeitgeber, especially blue wavelengths of length (Guido et al., 2010; Harvey et al., 2011). Other external zeitgebers, such as consistent social interactions or a work schedule, also entrain circadian rhythms (Frank, 2007; Guido et al., 2010). Blue light affects this pathway because the retina contains specific cells that use a photoreceptor, melanopsin, which is

particularly sensitive to blue wavelengths (Salva & Hartley, 2012). Melanopsin receptor cells connect from the eye to the body's master clock in the SCN (Macchi & Bruce, 2004; Wirz-Justice, 2007). Both exposure to daylight in the morning and exposure to artificial blue light can reset the body's biological clock through this pathway (Salva & Hartley, 2012; Vela-Bueno et al., 2007).

Two systems interact to control the sleep/wake cycle in humans: the homeostatic process (process S) and circadian rhythms (process C) (Asarnow et al., 2014; Harvey et al., 2011). The homeostatic process relies on the gradual increase of sleep pressure over the course of the day—making it more likely for a person to fall asleep—and the decrease of sleep pressure as a result of sleep (Salva & Hartley, 2012). The process C circadian rhythm aligns with day/night cycles, with light acting as a zeitgeber (Salva & Hartley, 2012). Light suppresses the SCN, pineal gland, and subsequent melatonin production; the melatonin suppression corresponds to the wake phase of the sleep/wake cycle. Darkness up-regulates the SCN, pineal gland, and melatonin and contributes to sleep onset and maintenance (Guido et al., 2010; Salva & Hartley, 2012; Vela-Bueno et al., 2007). Under normal conditions, process S and process C are synchronous and, as a result, sleep quality is the highest (Harvey et al., 2011; Salva & Hartley, 2012). When process S and process C become desynchronous, sleep can become disturbed (Asarnow et al., 2014; Harvey et al., 2011). Because artificial blue light acts on the circadian pathway, the sleep/wake circadian rhythm is particularly susceptible to disturbance by environmental influences. Artificial blue light has been shown to enhance feelings of alertness even at night (Revell et al., 2006; Sasseville et al., 2015), suppress melatonin (Lockley et al., 2003; Vela-Bueno et al., 2007), and delay phase of circadian rhythms (Lockley et al., 2003).

How Blue Light Effects Mood

Sleep disturbance is so common amongst those with mood dysregulation that it is considered one of the core symptoms of mood disorders (Salva & Hartley, 2012). At the sub-clinical level, sleep disturbance—which can be caused by excess blue light exposure—is linked to large increases negative mood (Harvey et al., 2011). Sleep disturbance not only increases negative emotional response, but also decreases positive emotional response (Harvey et al., 2011). Sleep disturbance also decreases medial-prefrontal cortex activity, which leads to impaired top down regulation and executive functioning, two important abilities for emotional control (Harvey et al., 2011).

Sleep disturbance modulates affect because the mechanisms that maintain adaptive affect—genes and neurotransmitters—are deeply intertwined with sleep/wake circadian rhythm maintenance. For instance, genes that are important for circadian rhythm creation and maintenance have been linked to bipolar disorder, major depressive disorder, and seasonal affective disorder (Harvey et al., 2011). Sleep disturbance from excess blue light causes disruptions in the oscillating transcription and translation of these shared genes, affecting mood (Harvey et al., 2011). Furthermore, neurotransmitters involved in mood psychopathology—serotonin and dopamine—are involved in the maintenance sleep/wake cycle and, themselves, oscillate in a 24-hour cycle. Serotonin plays a role in attention, cognition, and information processing (Harvey et al., 2011). Dysregulation of serotonin is a well-supported pathway to mood disorder, as serotonin plays a key role in the diathesis-stress model of depression, wherein interactions between environmental stress and serotonin polymorphisms confer greater risk for depression development (Harvey et al., 2011). The SCN contains a dense concentration of serotonergic receptors, and serotonin acts on the SCN to stabilize circadian rhythms (Harvey et al., 2011). Dually, circadian rhythms also modulate serotonin, as serotonin and serotonergic

receptor activity oscillate on a 24-hour cycle endogenously and are modulated by light and season (Harvey et al., 2011). This bidirectional circadian and serotonin interaction is a main feature of a conceptual model of depression as proposed by Mistlberger et al (Mistlberger et al., 2000).

Dopamine plays a role in motivation, reward processing, and pleasure dysregulation (Harvey et al., 2011). Dopamine dysregulation is strongly involved in mood disorders, and contributes to the flawed reward processing inherent to anhedonia, a core symptom of depression (Harvey et al., 2011). Dopamine, like serotonin, is linked to circadian rhythms maintenance in a number of ways. Dopaminergic reward activation and positive mood oscillate diurnally, indicating that they are controlled by circadian rhythms (Harvey et al., 2011). Dopamine, like serotonin, helps entrain circadian rhythms in the pathway from the retina to the SCN (Harvey et al., 2011). An additional way that dopamine is linked to sleep/wake circadian rhythms is through melatonin, which downregulates dopamine release; excess dopamine, dually, downregulates melatonin synthesis (Guido et al., 2010). Additionally, dopamine is linked to the sleep/wake circadian rhythm through light, which upregulates dopamine production in the retina (Guido et al., 2010). Dopamine plays a major role in regulating the retinal circadian clock so that the retinal cones receive much less light at night than during the day (Ribelayga et al., 2008). In sum, a large body of evidence supports that both serotonin and dopamine are deeply involved in circadian rhythms and sleep, outlining a mechanism through which sleep and circadian rhythm disruption can impact mood.

Interventions for Sleep and Mood Improvement

Inappropriately timed or irregular exposure to light and dark plays a large role in the pathology of mood disorders and in emotional dysregulation (Asarnow et al., 2014; Harvey et al.,

2011). However, process C and process S, which control the sleep/wake cycle, are open systems that respond to environmental stimuli; this is promising therapeutically, as it is possible to modify mood through controlling light and sleep (Asarnow et al., 2014; Harvey et al., 2011). For example, serotonin and dopamine are both circadian rhythms controlled by the SCN, which is modulated by light conditions. Therefore, interventions that modulate light, especially blue light, should impact these neurotransmitters and subsequent mood non-pharmacologically.

Benzodiazepines are the most commonly prescribed medication for sleep regulation, and while they are effective, they also are highly addictive, and patients easily become tolerant to them (Riemann et al., 2015). Antihistamines are also commonly prescribed for sleep regulation, and though they are not addictive, they are associated with liver and heart dysfunction, in addition to other side-effects (Riemann et al., 2015). Exogenous melatonin is also often administered for the regulation of sleep, but studies so far show only minor positive changes in sleep duration, quality, and onset latency (Salva & Hartley, 2012; Vela-Bueno et al., 2007). Given that the most commonly prescribed medications for addressing sleep disturbance are either not suitable for long-term use or do not make substantial improvements to sleep disturbances, non-pharmacological options for sleep hygiene are needed.

Two common psychotherapies designed to address sleep disturbance aim to enhance consistent in sleep hygiene and daily routine. Cognitive Behavioral Therapy for Insomnia (CBT-I) aims to improve sleep habits and hygiene, as well as address anxieties about sleep that exacerbate sleep disturbance (Mitchell et al., 2012). CBT-I effect sizes range from comparable to more effective at improving sleep hygiene and mood symptoms than common pharmacological treatments (Asarnow et al., 2014). Interpersonal and Social Rhythm Therapy (IPSRT) aims to regulate social and interpersonal zeitgebers (e.g. daily routine, romantic relationships) (Frank,

2007), the disturbance of which also often disturb the rhythmicity of exposure to stronger zeitgebers, such as light (Asarnow et al., 2014). There is only evidence that IPSRT is effective for the amelioration of bipolar disorder symptoms, though it is hypothesized to also effectively treat depressive symptoms (Asarnow et al., 2014).

Light and dark therapy interventions—bright light exposure and light restriction—are also common treatments designed to ameliorate sleep disturbance. The aims of light therapy are to resynchronize the circadian clock with the day/night cycle, to align sleep and wake with desired times, and to enhance mood (Wirz-Justice, 2007). Bright light exposure, in which patients are exposed to bright light in concordance with their circadian rhythms, is effective at relieving symptoms associated with seasonal depression, major depressive disorder, suicidal ideation, post-partum depression, and chronic fatigue (Asarnow et al., 2014; Salva & Hartley, 2012). Bright light exposure also delays sleep phase, enhances alertness, and delays melatonin rhythms (Lockley et al., 2003; Revell et al., 2006).

Light restriction interventions aim to reduce exposure to bright light, especially blue light, approaching sleep in concordance with natural circadian rhythm (Asarnow et al., 2014). Foundational light restriction therapies placed patients in complete darkness, and were used to successfully reduce manic symptoms in patients with bipolar disorder (Asarnow et al., 2014). More modern techniques of light reduction involve the filtering of blue wavelength of light with amber glasses during the evening (Burkhart & Phelps, 2009). One study found that amber glasses worn before sleep thwarted LED-induced melatonin suppression, increased subjective sleepiness, and decreased alertness, indicating that blue glasses successfully reduce signal to the SCN (van der Lely et al., 2015). Similar studies have replicated these sleep quality improvements, and found additional mood improvements (Kimberly & James R., 2009). Other similar studies report

no significant differences between control and experimental conditions on sleep quality or mood measures (Esaki et al., 2017). Amber glasses are typically used as an adjunct treatment for mood disturbances, and aside from the occasionally reported head discomfort, amber glasses are safe for long-term use (Esaki et al., 2016; Salva & Hartley, 2012). The current dearth of randomized control trails assessing the effect of blue-blocking amber glasses on sleep and mood, especially on those with sub-clinical sleep and mood concerns, limit the ability to draw conclusions on the efficacy of this intervention.

The Present Study: Effects of Amber Glasses on Melatonin, Sleep, and Mood

The present study aims to evaluate the effect of blue-light-blocking amber glasses on sleep duration, quality, efficiency, and latency, and affect over the course of many nights of sleep. We hypothesized that people in the amber glasses condition will show significantly better quality of sleep based on both subjective report (e.g. sleep diary, daily ratings of energy) as well as objective measures (e.g. actigraphy and oximetry). We also hypothesized that participants in the amber condition will show significantly more positive affect, and lower negative affect (depression and irritability), based on subjective report using well established rating scales. Exploratory aims include looking at the agreement between subjective (sleep diary, energy ratings) and objective (actigraphy and oximetry) measures of sleep constructs. This study will provide more evidence in the evaluation of amber glasses as a helpful adjunct treatment for those with sub-clinical levels of sleep and mood concerns.

Method

Participants

The 15 participants included in this study were a community sample. Participants were recruited through flyers and website recruitment ads targeting adults in the Chapel Hill

community. Participants interested in the study were encouraged to e-mail or call the study coordinator for additional information about participating in the study. Participants received $100 in compensation at the end of each week during their participation. Participants received a $50 bonus at the end of the study for completing all questionnaires and the sleep log. Participants were provided with parking for two nights in the sleep lab. Additionally, participants were given $15 for an evening meal each night while in the sleep laboratory as well as provided with breakfast food in the morning.

Inclusion criteria for participants were that they were in good physical health and proficient in written and spoken English. Participants also must have reported average total sleep time of less than 9 hours a night so that nights spent in the sleep lab would not result in sleep deprivation. Exclusion criteria included: taking regular medication affecting sleep and/or mood; traveling across more than two time zones within the past month; smoking more than 5 cigarettes per day; using caffeine excessively (more than 2 cups at one time or >500 mg daily); having a current DSM-5 Disorder; using street drugs at the time of the study; having a history of sleep disorder, bipolar disorder, psychosis, or seizure disorder; having chronic medical condition; and working under a night shift schedule within the past 2 months. Exclusion criteria were based on factors that might change melatonin production, thus altering sleep/wake circadian rhythms, not factors that would change risk of participation.

Measures and Equipment

State Affect. The Positive and Negative Affective Schedule (PANAS) (Watson et al., 1988) was used to assess state affect twice each day. The PANAS consists of 20 items, 10 of which assess positive affect (e.g. inspired, active, attentive) and 10 of which assess negative affect (e.g. guilty, scared, hostile). Items are rated from a scale of 1 (Very slightly or not at all) to 5

(Extremely) for how participants feel at the moment. Higher scores correspond to higher levels of positive or negative affect. Cronbach's alpha for the negative affect items was .87 and Cronbach's alpha for the positive affect items was .90 in the original sample (Watson et al., 1988). Percentage of Maximum Possible (POMP) scores were computed for each of the two subscales to aid in ease of interpretation.

Subjective Measures of Sleep. Participants filled out two subjective measures of sleep every day, and one extra subjective measure of sleep on the two sleep lab days only. Participants filled out the Leeds Sleep Evaluation Questionnaire (LSEQ) every morning for the 14 days of the study (Parrott & Hindmarch, 1978) to examine sleep quality and latency. The LSEQ is a 10 item, subjective, self-report questionnaire with items rated on a sliding scale between two options. For example, one question assessing ease of getting to sleep (i.e. "How would you describe the way you fell asleep last night in comparison to usual?") is answered on sliding scales between "*more difficult than usual*" and "*easier than usual*." The LSEQ can be scored on three different subscales, each of which examines a different aspect of sleep: ease of getting to sleep (GTS subscale; items 1-3), overall quality of sleep (QOS subscale; items 4 and 5), and behavior following wakening (BFW subscale; items 8-10). Percentage of Maximum Possible (POMP) scores were computed for each of the four subscales to aid in ease of interpretation. In this study, the GTS subscale is used to measure sleep latency, and the other two LSEQ subscales are used to measure sleep quality. The GTS subscale is rated such that higher scores indicate more ease in falling asleep, or lower sleep latency. The QOS subscale is rated such that higher scores indicate better overall sleep quality. The BFW is rated such that higher scores indicate more alertness and more coordination upon waking.

Participants filled out the Pittsburgh Sleep Quality Index (PSQI) twice—once in the morning and once in the evening—on each of the two sleep lab days. The PSQI measured sleep duration, latency, and quality over the course of the week prior. The PSQI is a 20 item, subjective, self-report questionnaire with several kinds of items. One item asks participants to average sleep duration during the week, and one item asks participants to estimate the average time it took them to fall asleep, or sleep latency. One item asks participants to rate their sleep quality over all; this item is rated on a scale from 1 (*very good*) to 4 (*very bad*).

Objective Measures of Sleep. Two objective biological measures of sleep were used in this study: GENEActiv and WatchPAT 300 devices. Participants were asked to wear Activinsights GENEActiv actigraphy watches every day for the duration of the 14-day study. GENEActiv watches measured movement, light exposure, and body temperature. Using the GENEActiv Sleep Macro v31 in Excel produced by the GENEActiv manufacturer, summary statistics of sleep duration and efficiency were determined for each of the 14 days of the study.

WatchPAT 300 devices from the Biobehavior Lab at the School of Nursing at UNC, the sleep lab where the participants slept for Sleep Phase I and II, were used to objectively measure sleep in addition to the GENEActiv devices. The WatchPAT 300 devices were used to noninvasively and objectively measure sleep using peripheral arterial tone and oxygen perfusion. Data from WatchPAT 300 were analyzed by the WatchPAT 300 software and the following summary statistics were computed: sleep duration in minutes, sleep latency (time in minutes between getting in bed and falling asleep), and number awakenings during the night, REM latency (time between falling asleep and start of first REM period), mean oxygen saturation of blood over the course of a night of sleep (higher scores indicating more perfusion), and mean heart rate over the course of a night of sleep.

Colored Lenses. Participants wore Uvex Skyper Anti-Fog Safety Glasses with grey lenses (S2821XP) and with amber lenses (S1933X). Participants were randomized to a starting color for the first glasses phase (three days), then switched to the other glasses color for the second glasses phase (three days). Transmittance analyses were conducted testing different lenses on their ability to block blue light (Figure 1). The amber glasses chosen for this study were selected for their superior ability to block blue light from entering the eye, blocking most of wavelengths the typically stimulate neural pathways connected to the SCN (<550 nm), while simultaneously allowing transmittance of other wavelengths (Esaki et al., 2016)(Figure 1). Grey lenses were chosen for the control condition to account for any effect on target metrics of merely wearing the glasses. Additionally, the grey lenses do not preferentially block short, blue wavelengths from entering the eye.

Procedures and Design

Participants in this study completed a 14-day balanced crossover design, in which each participant received the hypothesized active condition—amber glasses—as well as the control condition—grey glasses. This experiment consisted of six distinct phases over 14 days: Baseline (Day 0-3), Glasses Phase I (Day 4-6), Sleep Lab I (Day 7), Washout Phase (Day 8-10), Glasses Phase II (Day 11-13), and Sleep Lab II (Day 14). In each phase, participants were under distinct conditions and be administered distinct surveys (Figure 2). Participants responded to flyers and website advertisements and first completed a phone screen questionnaire with study staff to determine eligibility. Eligible participants then met with study staff to enroll, which started the baseline phase (Days 0-3). At enrollment, staff explained the details of the study and required participants to review consent documents. Consenting participants completed a demographics form, LSEQ, and PANAS; participants also reported the usual times they fall asleep and wake

up. Participants were also given equipment (i.e., GENEActiv watch and glasses) and provided with information on proper use. The GENEActiv watches were worn by participants for all 14 days of the study, but the glasses were worn by participants on only designated phases of the study. Participants completed two rounds of daily measures of sleep and mood (i.e., LSEQ, PANAS) each day—once in the morning and once in the evening. Participants also wore the GENEActiv watch and reported times they fell asleep and woke up for the remainder of the baseline phase.

During Glasses Phase I (Days 4-6), participants wore the pair of glasses to which they were first randomly assigned (i.e., amber or placebo control). Participants were instructed to put the glasses on three hours prior to their desired sleep onset time and to send a photograph of themselves wearing the glasses to the study coordinator to confirm protocol compliance. Participants continued to fill out daily measures of sleep and mood.

For the Sleep Lab I phase (Day 7), participants reported to the sleep laboratory 5 hours prior to their average sleep onset time. Participants slept in the laboratory overnight, spending roughly 12 hours in the sleep laboratory. Participants completed the evening daily measures of sleep and mood as usual. Participants were instructed to wear the glasses worn for the preceding three days three hours prior to sleep onset time. Participants wore the WatchPAT 300 while in the sleep laboratory. Participants left the sleep laboratory in the morning and begin the next phase of the study.

The Washout Phase (Day 8-10) required participants to follow similar protocol to the Baseline Phase. During this phase, participants completed measures on sleep, mood, and somatic complaints twice daily. Participants also continued to wear the GENEActiv watches, but did not wear the glasses. During Glasses Phase II (Dap 11-13), participants repeated the same protocol

as from Glasses Phase I except they switched their glasses color condition (i.e., participants who wore amber glasses during Glasses Phase I wore grey glasses during Glasses Phase II). During Sleep Lab II (Day 14), participants followed the same protocol as in Sleep Phase I except that they continued to wear the second shade of glasses. After Sleep Phase II, participants returned all their materials, were debriefed, and received their compensation.

Data Analytic Plan

Data Rearrangement and Manipulation. Data were rearranged to allow for longitudinal analyses that are dependent on long format data. Random missing values were ignored in linear mixed effects regression (LMER). Participants with random missing values were excluded from *t*-test analyses.

Preliminary Analyses. Preliminary analyses characterized the data and checked assumptions of kurtosis and skew. This included determining demographic information about age and gender of the participants, as well as identifying missing data.

Linear Mixed-Effects Regression Analyses. Linear mixed-effects regression models for repeated measures were used to examine within-person change imparted by the amber glasses active condition on several outcome variables. The outcome variables on which this type of analysis was conducted were outcome variables measured everyday (e.g. PANAS negative and positive affect; GENEActiv sleep duration, efficiency; LSEQ sleep subscales) rather than only on sleep lab days. Linear mixed-effect modeling is preferable over other repeated measures analyses for these data as it accounts for natural within-person differences in baseline sleep behavior and mood, as outcome measures are nested within individuals before being compared across groups. Analyses were completed with the *nlme* package in R (Long, 2012). The models allowed for random intercepts and random slopes, as baseline measurement and rate of change of

each outcome variable were likely to vary between participants. The models tested for the fixed effects of day, condition, and day*condition on each outcome variable. As random effects for each model, we only had intercepts for subjects, as detecting the random effects of other variables required more power than we had given our small participants pool. *P*-values for each beta estimate were obtained by converting from the given *t* in the output. The chi-square values and *p*-values for each model were obtained through model likelihood ratio tests of the full models with the effect against the respective null models.

T-Test and Cohen's d Analyses. Paired-samples *t*-tests were used to examine the within-person differences between the control grey glasses condition and the active amber glasses condition for all outcome variables measured only on the two sleep lab days (e.g., WatchPAT sleep duration, sleep latency, REM latency, number wakes, mean pulse, and mean oxygen saturation; PSQI sleep quality, duration, and latency). Participants who did not have data for both sleep lab phases were excluded from these analyses. As the sample size was low, Cohen's *d* effect sizes were computed to accompany each *t*-test to provide more information about the effect of the condition on each outcome variable.

Aim 1. The first aim of this study was to evaluate the effects of amber glasses on key outcome measures of sleep: quality, duration, efficiency, and latency. As data from the WatchPAT 300 and PSQI were collected on only two occasions—once in the active condition and once in the control condition—*t*-tests evaluated group mean differences in the summary statistics. As the GENEActiv, LSEQ, and self-report sleep duration data were hierarchical in structure and longitudinal, linear mixed-effects regression models were used to test within-person change as a result of the amber glasses.

We hypothesized that participants in the amber glasses condition would show significantly better quality of sleep based on subjective report (e.g., LSEQ, PSQI). We also predict that participants in the amber glasses condition will show longer sleep duration (e.g., GENEActiv, PSQI, daily self-report, WatchPAT), shorter sleep latency (e.g., WatchPAT, PSQI, LSEQ), and greater sleep efficiency (e.g., GENEActiv). We did not have hypothesized expectations for the effects of amber glasses on other criteria measured by the WatchPAT 300.

Aim 2. The second aim of this study was to evaluate the effects of amber glasses on key outcome measures of positive and negative affect as measured by the PANAS. Affect measures were evaluated on multiple occasions before and after participants received the amber glasses intervention. As data from the affect measures were hierarchical in structure and longitudinal, linear mixed-effects regression models were used to test within-person change as a result of the amber glasses. We hypothesized that the amber condition will show significantly more positive affect, and significantly lower negative affect compared to baseline, and that those in the grey glasses control condition would not show such benefits.

Exploratory Aims. Dimensions of sleep are often difficult to measure, and results often differ due to both varying method and time of day of measurement (Meltzer, 2020). As this study includes a wide variety of methods to study sleep constructs, an exploratory aim of this study was to evaluate the agreement between subjective (LSEQ and PSQI) and objective (GENEActiv and WatchPAT) measures of sleep across duration, quality, and latency constructs. Agreement was also evaluated between the same measure of sleep quality and latency (PSQI) administered at two different times during the day. Correlation analyses quantified agreement.

Results

A total of 15 participants, 10 males and 5 females from age 18 to 47 (*M*=27.07, *SD*=7.17), enrolled in the study who met inclusion and exclusion criteria. These 15 participants each completed amber glasses intervention, a control grey glasses condition, and baseline phase, and a washout phase. Every day during the 14-day study, these participants completed daily surveys of mood and sleep, and wore GENEActiv watches that monitored sleep. Twice during the study, at the end of each glasses phase, the 15 participants slept in the sleep laboratory, where they completed additional surveys and objective monitoring of sleep by WatchPAT 300 devices. Descriptive statistics for all of the predictor and outcome variables are listed in Table 1. As the PANAS and PSQI surveys were given twice per day—one in the morning and once at night—AM and PM scores were calculated separately for each participant.

Sleep Quality

The two measures of sleep quality included in this study were two daily estimates from the LSEQ (BFW and QOS subscales) and a weekly sleep quality rating from the PSQI. The effect of day, condition, and a day by condition interaction on LSEQ Behavior Following Waking (BFW) POMP scores was determined using linear mixed-effects regression models ($\chi^2(1)=3.74$, $p=0.81$). The intercept of predicted LSEQ Behavior Following Waking (BFW) POMP scores varied between participants, *SD*= .05, *ICC*=.34. Figure 3 shows the spaghetti plots of LSEQ BFW POMP scores by condition with trend lines for each participant as linear regressions, and Figure 4 shows the spaghetti plots of LSEQ BFW POMP scores by condition showing the high variability within participant. Table 2 displays the regression weights. The intercept was significantly different than zero, indicating that the average participant's initial LSEQ BFW POMP score was 51% of the maximum possible score. No significant effects from day, condition, or day*condition on LSEQ BFW POMP scores were found.

The effect of day, condition, and a day by condition interaction on LSEQ Quality of Sleep (QOS) POMP scores was also determined using linear mixed-effects regression models ($\chi^2(1)=17.68$, $p=0.01$). The intercept of predicted LSEQ Quality of Sleep (QOS) POMP scores varied between participants, $SD= .06$, $ICC=.30$. Figure 3 shows the spaghetti plots of LSEQ QOS POMP scores by condition with trend lines for each participant as linear regressions, and Figure 4 shows the spaghetti plots of LSEQ QOS POMP scores by condition showing the spread of data by participant. Beta weights are displayed in Table 3. Intercept was significantly different than zero, indicating that the average participant's LSEQ QOS POMP score was 59% of the maximum possible score. While allowing intercepts and slopes to vary randomly, there was no significant effect of day on LSEQ QOS POMP scores. There was a significant effect of the washout phase condition on LSEQ QOS POMP scores, predicting a 92% initial decrease LSEQ QOS POMP score upon starting the washout phase. There was also a significant effect of the day and washout phase interaction, which indicates that participant's LSEQ QOS POMP scores increased 13% each day they spend in the washout phase condition.

The effect of condition on weekly ratings of sleep quality from PSQI was determined using paired-sample *t*-tests (Table 4). PSQI sleep quality ratings in the morning and evening were expected to agree, but these constructs were separated to ensure accuracy of analyses. The paired-sample *t*-tests for both AM and PM PSQI sleep quality ratings were not significant (Figure 5). However, the Cohen's *d* was small and positive, meaning PSQI sleep quality scores were higher for those in the grey condition than the amber condition. As higher scores on the sleep quality PSQI item indicate worse sleep quality, those in the amber condition had slightly better sleep quality than those in the grey glasses condition, though this difference was not significant.

Sleep Duration

The three measures of sleep duration included in this study were a daily estimate from GENEActiv, a weekly objective sleep duration estimate from the WatchPAT, and a weekly self-report sleep duration estimate from the PSQI. The effect of day, condition, and a day by condition interaction on GENEActiv sleep duration was determined using linear mixed-effects regression models ($\chi^2(1)=11.49$, $p=0.12$). The intercept of predicted GENEActiv sleep duration varied between participants, $SD= 1.30$, $ICC=.130$. Figure 6 shows the spaghetti plots of GENEActiv sleep duration by condition with trend lines for each participant as linear regressions, and Figure 7 shows the spaghetti plots of GENEActiv sleep duration by condition showing the spread of data by participant. Beta weights are displayed in Table 5. The intercept was significantly different than zero, indicating that for the average participant, initial GENEActiv sleep duration was 10.46 hours. While allowing intercepts and slopes to vary randomly, there was a significant effect of day on GENEActiv sleep duration, there was a significant effect of amber glasses on GENEActiv sleep duration, predicting a 1.76-hour initial decrease in sleep duration. There were no significant effects of day or the day by condition interaction on sleep duration as measured by the GENEActiv.

The effect of condition on weekly ratings of sleep duration from the WatchPAT and PSQI were determined using paired-sample *t*-tests (Table 4). The paired-sample *t*-test for WatchPAT sleep duration was approaching significance (Figure 8). The Cohen's *d* value was large and negative, indicating that participants slept longer when in the amber glasses condition than when they were in the grey glasses control condition. PSQI sleep duration ratings were collected in the morning and evening and expected to agree; all participants responded to the PSQI sleep duration item in the morning, but many skipped this item in the afternoon

administration. Therefore, only PSQI_AM ratings of sleep duration were analyzed. The paired-sample *t*-test for PSQI_AM sleep duration was not significant (Figure 8). The Cohen's *d* value was small and negative, indicating that participants slept marginally longer when in the amber glasses condition than when they were in the grey glasses control condition based on self-ratings.

Sleep Latency

The three measures of sleep latency included in this study were a daily ease of getting to sleep rating from the GTS subscale of the LSEQ, a weekly objective sleep latency estimate from the WatchPAT, and a weekly self-report sleep latency estimate from the PSQI. The effect of day, condition, and a day by condition interaction on LSEQ Getting to Sleep (GTS) POMP scores was determined using linear mixed-effects regression models ($\chi^2(1)=12.50$, $p=0.09$). The intercept of predicted LSEQ Getting to Sleep (GTS) POMP scores varied between participants, $SD= .08$, $ICC=.42$. Figure 9 shows the spaghetti plots of LSEQ GTS POMP scores by condition with trend lines for each participant as linear regressions, and Figure 10 shows the spaghetti plots of LSEQ GTS POMP scores by condition showing the spread of data by participant. Beta weights are displayed in Table 6. The intercept was significantly different than zero, indicating that the average participant's initial LSEQ GTS POMP score was 64% of the maximum possible score. There was a significant effect of the washout phase on GENEActiv sleep duration, predicting a 57% initial decrease from baseline in LSEQ GTS POMP scores. Lower POMP scores on the LSEQ GTS sub scale indicate more trouble getting to sleep. There was no significant effect of day alone on LSEQ GTS POMP scores. However, there was a significant effect of the day and washout phase interaction on LSEQ GTS POMP score, which indicates that participant's LSEQ GTS POMP score increased 8% each day they spent in the washout phase, indicating increase in the ease of getting to sleep.

The effect of condition on weekly ratings of sleep latency from both the WatchPAT and the PSQI were determined using paired-sample *t*-tests (Table 4). The paired-sample *t*-test for WatchPAT sleep latency was insignificant (Figure 11). The Cohen's *d* of -.11 indicates that the amber glasses intervention had little to no differential effect on sleep latency of participants. Sleep quality ratings from the PSQI in the morning and evening were expected to agree, but these constructs were separated to ensure accuracy of analyses and reporting. The paired-sample *t*-tests for AM and PM PSQI sleep latency ratings were both insignificant (Figure 11). The Cohen's *d* effect sizes were positive for both AM and PM PSQI measurements; the Cohen's *d* was small for the AM PSQI self-report sleep latency and medium for PM PSQI self-report sleep latency. This indicates that participants had shorter sleep latency when under the amber glasses condition than under the grey glasses condition, though this difference was small and was not significant.

Sleep Efficiency

GENEActiv devices yielded the daily measure of sleep efficiency in this study. The effect of day, condition, and a day by condition interaction on GENEActiv sleep efficiency was determined using linear mixed-effects regression models ($\chi^2(1)=15.24$, $p=0.03$). The intercept of predicted GENEActiv sleep efficiency varied between participants, $SD= .07$, $ICC=.162$. Figure 12 shows the spaghetti plots of GENEActiv sleep efficiency by condition with trend lines for each participant as linear regressions, and Figure 13 shows the spaghetti plots of GENEActiv sleep efficiency by condition showing the spread of data by participant. Beta weights are displayed in Table 7. The intercept was significantly different than zero, indicating that the average participant's initial GENEActiv sleep efficiency was 64%. No significant effects from day, condition, or the day by condition interaction on GENEActiv sleep efficiency were found.

Other Sleep Constructs

The weekly measurements from the WatchPAT on both sleep lab phases yielded summary statistics for several other sleep-related constructs: REM latency, number of wakes during the night, mean pulse, and mean blood oxygen saturation (Table 4). The paired-sample *t*-test for REM latency was insignificant (Figure 14). The Cohen's *d* for this *t*-test was medium and positive, indicating that when in the amber glasses condition, participants had a shorter REM latency than when in the grey glasses condition. The paired-sample *t*-test for number of wakes during sleep was insignificant (Figure 14). The Cohen's *d* is for this *t*-test was medium and negative, indicating that those in the grey glasses control condition woke up less during the night than when in the amber glasses condition. The paired-sample *t*-test for mean pulse during sleep was insignificant (Figure 14). The Cohen's *d* of .09 for this *t*-test indicates that the intervention had no effect on mean pulse of participants over the course of a night's sleep regardless of their assigned condition. The paired-sample *t*-test for mean blood oxygen saturation was insignificant (Figure 14). The Cohen's *d* for this *t*-test was small and negative, indicating that participants had slightly higher mean oxygen saturation in their blood during sleep when they were in the amber glasses condition than when they were in the grey glasses condition.

Positive Affect

The positive affect subscale of the PANAS was used as the daily measurement of positive affect in this study. Affect ratings from the PANAS in the morning and evening were not expected to agree, as affect generally changes throughout the day (Clark et al., 1989); therefore, these constructs were separated to ensure accuracy of analyses and reporting. PANAS positive affect subscale scores were converted to percentage of maximum possible (POMP) scores, with higher scores indicating more positive affect.

The intercept of predicted morning ratings of positive affect from the PANAS varied between participants, *SD*= .09, *ICC*=.57. Figure 15 shows the spaghetti plots of PANAS AM positive affect by condition with trend lines for each participant as linear regressions, and Figure 16 shows the spaghetti plots of PANAS AM positive affect by condition showing the spread of data by participant. Beta weights are displayed in Table 8, $\chi^2(1)=13.81$, $p=0.05$. Intercept was significantly different than zero, indicating that the average participant's PANAS AM positive affect score was 38% of the maximum score possible. Higher scores of the PANAS positive affect subscale indicate more positive affect. There was no significant effect of day, condition, or day*condition on AM ratings of positive affect.

The intercept of predicted evening ratings of positive affect from the PANAS varied between participants, *SD*= .08, *ICC*=.57. Figure 15 shows the spaghetti plots of PANAS PM positive affect by condition with trend lines for each participant as linear regressions, and Figure 16 shows the spaghetti plots of PANAS PM positive affect by condition showing the spread of data by participant. Beta weights are displayed in Table 9, $\chi^2(1)=27.36$, $p=0.0003$. The intercept was significantly different than zero, indicating that the average participant's PANAS PM positive affect score was 38% of the maximum score possible. There was no significant effect of day or day*condition on evening ratings of PANAS positive affect. However, there were significant effects of amber glasses on evening ratings of PANAS positive affect, predicting an 8% initial increase in PANAS positive affect POMP score upon starting the amber glasses condition.

Negative Affect

The negative affect subscale of the PANAS was used as the daily measurement of negative affect in this study. Affect ratings from the PANAS in the morning and evening were

not expected to agree, as affect generally changes throughout the day (Clark et al., 1989); therefore, these constructs were separated to ensure accuracy of analyses and reporting. PANAS negative affect subscale scores were converted to percentage of maximum possible (POMP) scores, with higher scores indicating more negative affect.

The intercept of predicted morning ratings of negative affect from the PANAS varied between participants, *SD*= .01, *ICC*=.33. Figure 15 shows the spaghetti plots of PANAS AM negative affect by condition with trend lines for each participant as linear regressions, and Figure 16 shows the spaghetti plots of PANAS AM negative affect by condition showing the spread of data by participant. Beta weights are displayed in Table 10, $\chi^2(1)=11.04$, $p=0.14$. The intercept was significantly different than zero, indicating that the average participant's PANAS AM negative affect score was 25% of the maximum score possible. While allowing intercepts and slopes to vary randomly, there was a significant effect of day on PANAS AM negative affect, predicting an 1% decrease in negative affect each day the participant is in any condition (amber, grey, or washout) compared to baseline. Additionally, there was a significant effect of amber glasses on AM negative affect, predicting a 3% initial decrease in negative affect upon starting the amber glasses condition. There was also a significant effect of grey glasses on AM negative affect, predicting a 2% initial decrease in negative affect upon starting the amber glasses condition. Lastly, there were significant effects of the day and amber glasses interaction, the day and grey glasses interaction, and the day and washout phase interaction, which indicate that participant's AM negative affect increased 1%, 1%, and 2% of the maximum possible score, respectively, each day they spent in each condition.

The intercept of predicted evening ratings of negative affect from the PANAS varied between participants, *SD*= .02, *ICC*=.32. Figure 15 shows the spaghetti plots of PANAS PM

negative affect by condition with trend lines for each participant as linear regressions, and Figure 16 shows the spaghetti plots of PANAS PM negative affect by condition showing the spread of data by participant. Beta weights are displayed in Table 11, $\chi^2(1)=2.07$, $p=0.96$. Intercept was significantly different than zero, indicating that the average participant's PANAS PM negative affect score was 23% of the maximum score possible. Higher scores of the PANAS negative affect subscale indicate more negative affect. There was no significant effect of day, condition, or day*condition on PM ratings of negative affect.

Sleep Measures Agreement

To analyze the agreement between different measurements of sleep duration, sleep quality, and sleep latency, Pearson *r* correlations were calculated between the multiple measures of these constructs; see Figure 17. Sleep duration measures all had a small to large positive correlations with one another (e.g., $r=.26$ between GENEActiv and WatchPAT), which indicates good agreement overall between these measures. For the sleep quality construct, SQ_PSQI_AM and SQ_PSQI_PM items were reverse scored so that higher scores indicate more sleep quality. Therefore, agreement amongst sleep quality measures is indicated by positive correlations. For the sleep quality measures, there are disagreements not only between the LSEQ and PSQI measurements of sleep quality (e.g., $r= -.13$ between LSEQ_QOS and PSQI_PM), but there is also disagreement within different subscales of the LSEQ (e.g., $r=.02$ between LSEQ_BFW and LSEQ_QOS) and between the PSQI measured at different times of day (e.g., PSQI_AM correlates $r= .22$ with LSEQ_BFW but PSQI_PM correlates $r= -.1$ with LSEQ_BFW). This indicates large discrepancies between different self-report measures of sleep quality, and that self-rated sleep quality is sensitive to time of day when reporting. For the sleep latency construct, SL_LSEQ_GTS items are normally scored such that higher scores indicate greater ease in falling

asleep (low sleep latency), which is the opposite of the other sleep latency estimates. Therefore, the SL_LSEQ_GTS were reverse scored so that lower scores indicate lower sleep latency. With these adjustments, agreement between the sleep latency measures would be indicated by positive correlations. The SL_LSEQ_GTS had small negative correlations with the other sleep latency (e.g., r=-.21 between LSEQ_GTS (self-report) and WatchPAT (objective)), indicating that the LSEQ measurement of sleep latency does not agree with the other sleep latency measures. The PSQI and WatchPAT measures of sleep latency had medium positive correlations, showing strong agreement between these measures (e.g., r=.45 between WatchPAT (objective) and PSQI_AM (self-report)). Notably, the PSQI_AM and PSQI_PM measures of sleep latency had strong agreement (r=.97), indicating similar self-report estimates of sleep latency regardless of the time of day when participants were measured.

Discussion

This study aimed to elucidate the effect of an amber glasses intervention on sleep and affect. This is one of the first studies to test the effect of an amber glasses intervention on affect and sleep using both self-report and objective measures. We hypothesized that participants in the amber glasses condition would show significantly higher sleep quality, longer sleep duration, shorter sleep latency and higher sleep efficiency both compared to baseline and compared to the grey glasses condition. All of these changes are desirable functionally, and would increase the mental and physical health of participants. We did not have specific hypotheses about the other sleep constructs measured in this study (e.g, REM latency, number of wakes, mean pulse, mean oxygen saturation). If our hypothesis were true, then we would expect the amber glasses to predict an immediate and sustained increase sleep quality, duration, and efficiency, as well as an immediate and sustained decrease in sleep latency. This would be indicated by a significant

amber glasses condition effect and by a significant amber condition by day interaction effect on each sleep outcome variable. Our results on sleep quality, sleep duration, sleep efficiency, and sleep latency generally do not support our hypotheses. No significant group differences were found amongst the other sleep constructs examined. However, some results are promising, and some of the null-results may be attributed to methodological shortcomings and analytical difficulties.

We also hypothesized that participants in the amber glasses condition would show significantly more positive affect and show significantly lower negative affect compared to baseline. Both of these changes are desirable functionally. We also hypothesized that those in the grey glasses condition would not show such benefits. If our hypothesis were true, then we would expect the amber glasses to predict an immediate and sustained increase positive affect, as well as an immediate and sustained decrease in negative affect. This would be indicated by a significant amber glasses condition effect and by a significant amber condition by day interaction effect on each outcome variable. Some aspects of our results do support our hypotheses, and novel differences were found between the effect of amber glasses on positive and negative affect alone and dependent on time of day. Specifically, we found that the effect of amber glasses was strongest for positive affect in the evening, but not in the morning. We also detected small, but non-exclusive, effects of amber glasses on morning negative affect.

The results from the analyses of the various sleep quality measures in the present study do not strongly support our hypotheses. Neither amber glasses nor the amber glasses by day interaction predicted significant increases in score for either the behavior following waking or the quality of sleep subscales of the LSEQ. The paired-sample *t*-tests for sleep quality measures were also non-significant, and the small effect sizes corresponding to these *t*-tests indicated only

slightly better sleep quality in amber glasses condition than the grey glasses condition. No adverse effects of amber glasses were found. Our results disagree with that of other studies, which indicated that all or many participants wearing amber glasses reported significantly higher sleep quality than controls (Burkhart & Phelps, 2009; Esaki et al., 2017).

The results of the analyses for sleep duration and sleep efficiency do not support our hypotheses, but also should be interpreted with hesitation due to analytical and methodological difficulties. Amber glasses significantly predicted an initial decrease in GENEActiv sleep duration, but the effect of the day by amber glasses interaction was not significant. This indicates that amber glasses had a strong immediate effect on participants by decreasing sleep duration, and that this effect did not change over the days in the amber glasses condition. Importantly, no other condition or day by condition interaction was significant, meaning the amber glasses exclusively had this adverse effect on participants. This effect is troublesome, as it may indicate that the amber glasses had a specific deleterious effect on participants. Dually, this effect is troublesome as it differs from the results of the *t*-tests in the present study, which indicated that on self-report and objective sleep duration measures, participants slept longer in the amber glasses condition. However, there is some literature that shows that similar blue-blocking lenses do reduce sleep duration, though non-significantly, relative to control lenses (Landers et al., 2009). The analyses for the GENEActiv sleep efficiency data indicated that there was no significant immediate or lasting effect amber glasses. GENEActiv data is difficult to analyze, as it difficult to differentiate extreme data from data resulting from participant non-compliance (i.e., participants forgetting to wear the device). Based off of the large spread in results of both the GENEActiv sleep duration (Figure 7) and sleep efficiency (Figure 13) summary statistics, it is clear that these summary statistics were influenced by participant non-compliance. GENEActiv

sleep duration data was modified before analyses were run to adjust for such non-compliance as much as possible, but some data points that are a result of non-compliance may have been left in the dataset because they could not reliably be differentiated from true scores. GENEActiv sleep efficiency data could not be equivalently modified. Due to difficulties in data cleaning for GENEActiv data, the results of the linear mixed effects regressions for GENEActiv sleep duration and efficiency should be interpreted with hesitation.

The results from the analyses of the various sleep latency measures in the present study do not strongly support our hypotheses. There were no significant effects of amber glasses or the amber glasses by day interaction on the getting to sleep subscale of the LSEQ. The paired-sample *t*-tests also found no significant group differences for sleep latency between the amber glasses and grey glasses condition. These findings are in contrast to other literature that found amber glasses to be effective at pushing sleep circadian rhythms and sleep onset forward, which would decrease sleep latency (Esaki et al., 2016). The washout phase and grey glasses condition did, however, predict significant—or approaching significant—decreases in the ease of getting to sleep. The adverse effects conferred on the participants by the grey glasses and washout phase was unexpected and troublesome. It is possible, though, that these adverse effects are driven by a loss of benefit of the amber glasses, or that they are Type 1 error.

Findings from the analyses of positive and negative affect did not fully support our original hypotheses, but do provide novel insight about the effectiveness of amber glasses on affect at different times of day. Amber glasses did not predict any changes in positive affect in the morning, but did predict an initial significant and notable increase in positive affect in the evening. Dually, no other condition predicted significant changes in positive affect in the evening. Amber glasses did not predict changes in evening negative affect, but did predict a

small significant decrease in negative affect in the morning. However, grey glasses and the washout phase also predicted similar decreases in morning negative affect; therefore, this effect may not be exclusive to amber glasses. One explanation is that baseline morning negative affect was randomly higher than typical (Figure 16), thus resulting in decreases in negative affect over the rest of the study and Type 1 error. Regardless, the low betas associated with these significant findings indicate only minimal decreases in participants' negative affect, which is not clinically meaningful.

In all, these findings provide evidence in support of our positive affect hypothesis, provide some preliminary support for our negative affect hypothesis, and provide a novel finding about the particular effectiveness of amber glasses on evening positive affect. These results agree with findings from other amber glasses studies (Burkhart & Phelps, 2009). Our results corroborate and could be explained by findings that positive affect, but not negative affect, varies diurnally, indicating that positive affect is more directly controlled by circadian rhythms, which amber glasses manipulate (Clark et al., 1989). Amber glasses have been found to significantly decrease negative mood in other studies, however, this effect was found in participants with mood disorders rather than participants without any DSM-5 diagnosis (Glickman et al., 2006; Henriksen et al., 2016).

In all, small sample size, large interpersonal variation, and some participant noncompliance limit the ability to draw conclusions from this feasibility study. Sleep and mood vary diurnally, however, the assumptions of the mixed-effect models used were linear growth over time. Many of the models run to predict each of the outcome variables via linear mixed-effects regression were not significantly superior to their respective null models. This is may be evidence that the assumptions of linear growth inherent to mixed-effects models may not fit the

data well. Autoregressive integrated moving average (ARIMA) is an example of a type of analysis that may be better suited to data of this kind, as ARIMA better accounts for the sinusoidal or curvilinear variation of many of the outcome variables. ARIMA requires at least 30 repeated measures of each outcome variable, so the methodology would need to be altered to allow such analyses. Ecological momentary assessment could enable more frequent assessment (Trull & Ebner-Priemer, 2013), as well as allow examination of known circadian variation in the outcome variables through ARIMA (Glickman et al., 2006; Henriksen et al., 2016). Future studies should use these modern methodologies to examine the effect of amber glasses on similar outcome variables. Dually, the lack of model fit may have been due to the small sample size, which limited the power to detect random between-participant variation in the outcome measures. As seen in the various spaghetti plots, there was a lot of between-participant variation, and if there were more power, the models could more accurately parse between random effects and the fixed effect of the intervention. Our small sample size may have also increased likelihood of Type II error. Future studies should aim to recruit more participants to negate such power issues.

Participant non-compliance surrounding daily use of the GENEActiv devices limited conclusions we could draw from such data. Though objective measures of sleep do have the potential to help sleep researchers overcome barriers related to self-report measurement, current limitations of GENEActiv use and analytic software (e.g. Macros sheet) make it an unreliable tool for daily objective sleep measurement. Future studies should aim to find more sophisticated methods to extract summary statistics from GENEActiv data, find ways to enhance participant compliance for these devices, and find new methods to objectively measure sleep over a longitudinal study.

To conclude, though the results of this study did not strongly support our hypotheses that amber glasses would increase sleep quality, duration, and efficiency and decrease sleep latency, our results did show both preliminary evidence that amber glasses could help decrease negative affect and strong evidence that amber glasses could increase positive affect, especially in the evening. Amber glasses have been shown in many studies to be an effective adjunct treatment for mood disorders, and this study provides more evidence that amber glasses may be helpful for individuals with sleep and mood concerns below the clinical level as well. Future studies with larger samples sizes, as well as more advanced methodology and analytical techniques, will help illuminate the true effect of amber glasses interventions on sleep and affect, and will help advance amber glasses as a viable treatment for those with sleep and mood concerns.

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Figure 1. Light transmittance for amber lenses used in this study. Wavelengths of light below approximately 550 nm act on the retinal pathway that modulates the SCN and subsequent circadian rhythms (Esaki et al., 2016).

Phase	Baseline				Glasses Phase I			Sleep Lab I	Washout Phase			Glasses Phase II			Sleep Lab II
Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PANAS	x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x
Leeds	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GENEActiv		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Self report fall asleep/wake up	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Glasses (Grey or Orange)					x	x	x	x				x	x	x	x
Watch PAT								x							x
PSQI								2x							2x

Figure 2. Example study timeline for a participant who received the amber glasses condition first, followed by the control grey glasses condition.

Table 1.
Descriptive statistics for all variables used

Construct	*Variable*	*N*	*Mean*	*SD*	*Min*	*Max*	*Range*	*Skew*	*Kurtosis*	*SE*
Predictor (Intervention Condition)	Condition	210	2.5	1.05	1	4	3	0	-1.22	0.07
Predictor (Time)	Day	210	2.21	1.66	0	5	5	0.03	-1.39	0.11
Sleep Duration	WatchPAT	30	372	46.54	214	453	239	-1.13	2.28	8.5
	GENEActiv	191	438.77	224.1	137	1440	1303	2.92	9.29	16.22
	PSQI_AM	30	7.1	1.19	3.71	9	5.29	-0.86	0.58	0.22
Sleep Quality	PSQI AM	21	1.71	0.72	1	3	2	0.43	-1.09	0.16
	PSQI PM	28	2.04	0.51	1	3	2	0.07	0.71	0.1
	LSEQ_QOS_POMP	205	0.53	0.16	0.08	1	0.92	0.22	0.31	0.01
	LSEQ_BFW_POMP	202	0.48	0.14	0.08	0.8	0.72	-0.26	-0.12	0.01
Sleep Latency	LSEQ_GTS_POMP	206	0.57	0.14	0.27	0.99	0.71	0.67	0.18	0.01
	WatchPAT	30	30.5	14.64	10	65	55	0.71	-0.73	2.67
	PSQI_AM	29	17.21	15.91	5	90	85	3.25	12.23	2.95
	PSQI_PM	27	19.41	27.20	5	150	145	4.07	16.71	5.23
Sleep Efficiency	GENEActiv	191	0.74	0.19	0.14	1	0.86	-1.06	0.53	0.01
Other Sleep Factors from WatchPAT	REM latency	29	101.9	57.17	33	213	180	0.79	-0.91	10.62
	Number wakes	30	6.07	3.14	2	14	12	0.46	-0.31	0.57
	Mean pulse	30	57.4	9.17	42	79	37	0.79	0.03	1.67
	Oxygen saturation	30	95.73	1.11	92	97	5	-1.23	2.06	0.2
Positive Affect PANAS	AM POMP	208	0.35	0.12	0.2	0.8	0.6	0.74	0.33	0.01
	PM POMP	199	0.37	0.12	0.2	0.76	0.56	0.67	0.21	0.01
Negative Affect PANAS	AM POMP	208	0.22	0.03	0.2	0.36	0.16	2.49	7.14	0
	PM POMP	199	0.22	0.04	0.2	0.48	0.28	3.57	16.47	0

Note: POMP = Percent of Maximum Possible; PSQI = Pittsburgh Sleep Quality Index; PANAS = Positive and Negative Affective Schedule; LSEQ = Leeds Sleep Evaluation Questionnaire; GTS= Getting to Sleep; QOS= Overall Quality of Sleep; BFW= Behavior Following Waking; SRFAWU= Self-Reported Fall Asleep Wake Up time

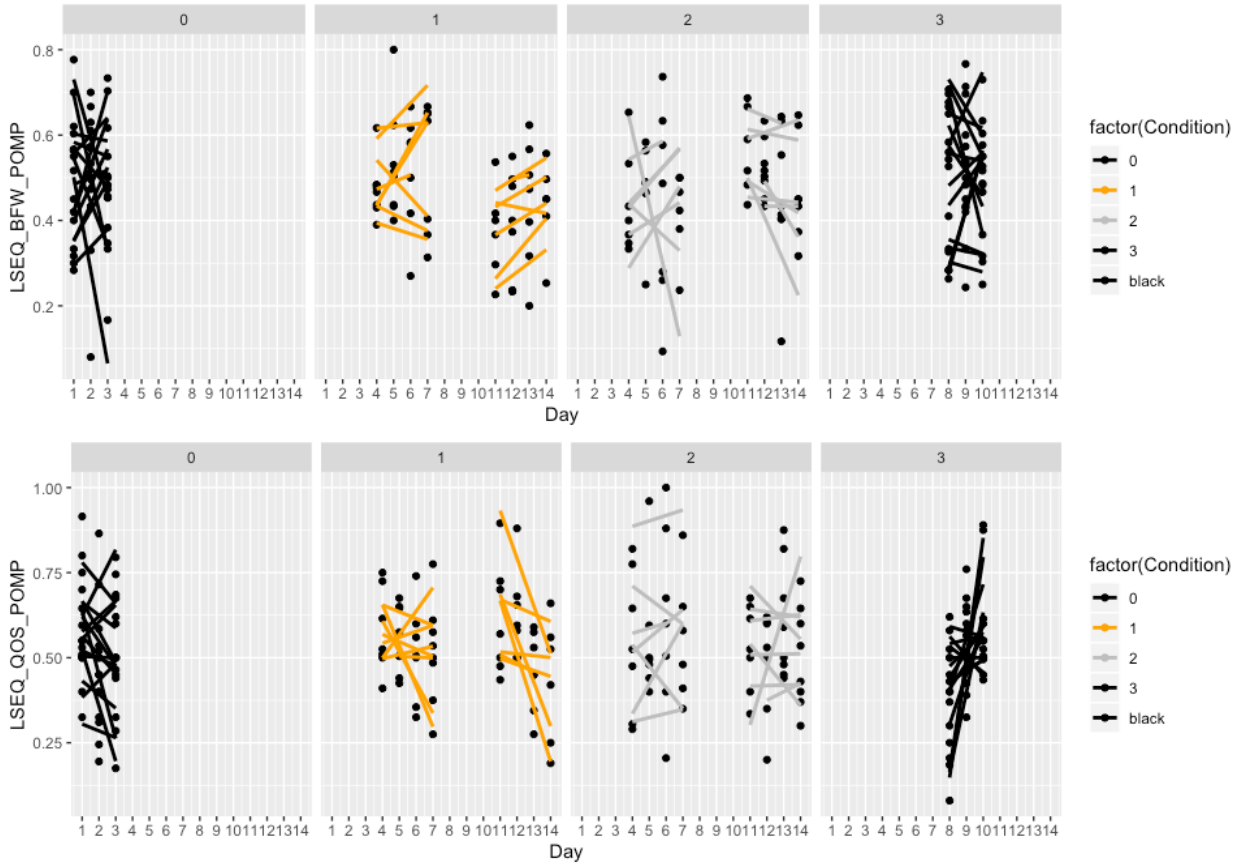

Figure 3. Spaghetti plots for sleep quality outcome variables by condition: LSEQ_BFW (Behavior Following Wakening) and LSEQ_QOS (Quality of Sleep). Trend lines are regressions for each participant showing changes in the outcome variable over the days in each condition. Colors represent the glasses conditions, the first panel represents baseline, and the fourth panel represents the washout phase. For LSEQ_BFW, there were no significant effects of day, condition, or the day by condition interaction. For LSEQ_QOS, there were significant effects of the washout phase, and the washout by day interaction, in that the washout condition caused significant immediate decrease in quality of sleep, but that participants QOS scores increased back to baseline levels as days in the condition passed.

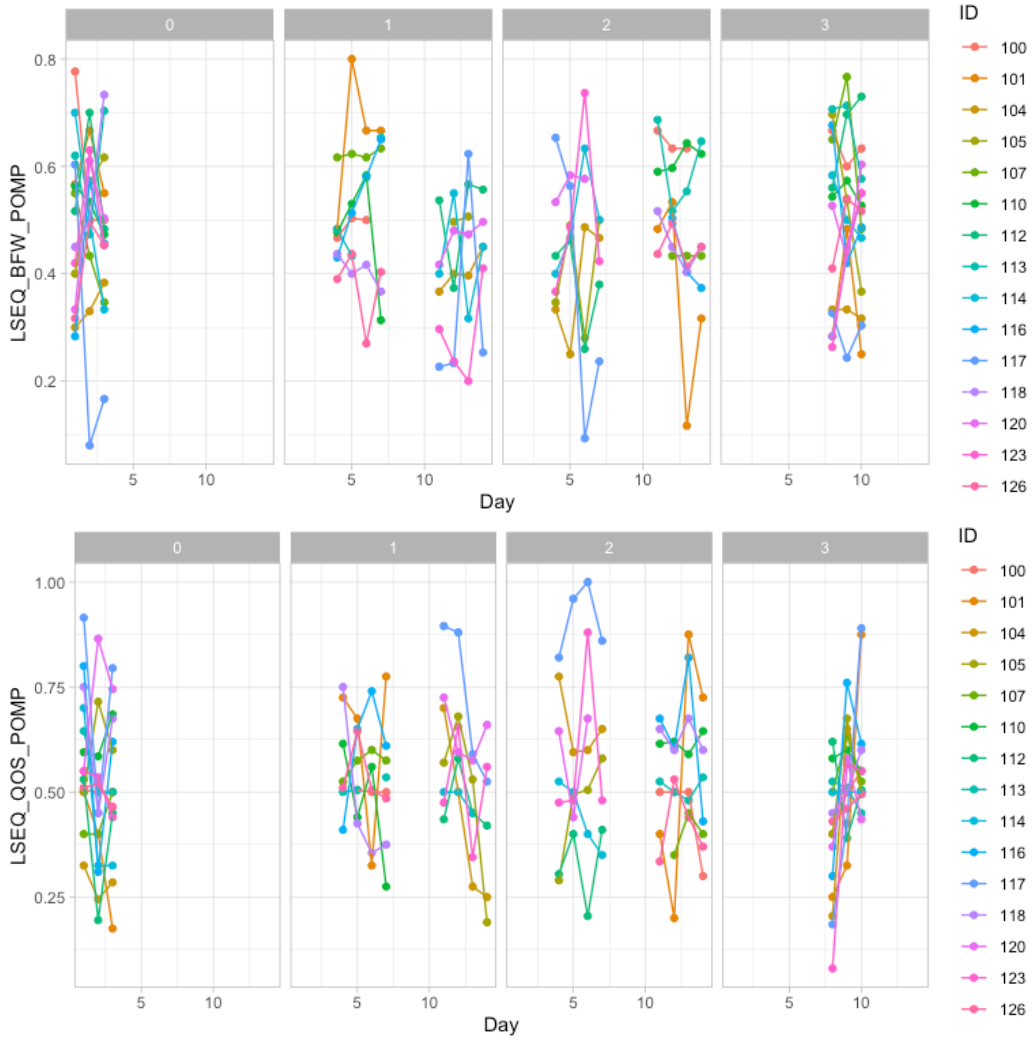

Figure 4. Spaghetti plots for sleep quality outcome variables by condition: LSEQ_BFW (Behavior Following Wakening) and LSEQ_QOS (Quality of Sleep). Trend lines connect the data points for each participant showing changes in the outcome variable over the days in each condition. Colors represent each participant. Panels 0 through 3 represent the baseline, amber glasses, grey glasses, and washout conditions, respectively. This shows the high amount of within-person variance across days and conditions.

Table 2.
Beta Weights Predicting Sleep Quality as measured by the LSEQ BFW (Behavior Following Wakening) subscale

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.51	0.05	10.11	202	**<.00005**	0.34
Day	-0.01	0.02	-0.37	202	0.36	
Amber Glasses	-0.00	0.07	-0.02	202	0.49	
Grey Glasses	-0.03	0.07	-0.38	202	0.35	
Washout	0.04	0.21	0.19	202	0.42	
Day*Amber Glasses	0.00	0.02	0.15	202	0.34	
Day*Grey Glasses	0.01	0.02	0.31	202	0.38	
Day*Washout	0.00	0.03	0.10	202	0.46	

Table 3.
Beta Weights Predicting Sleep Quality as measured by the LSEQ QOS (Quality of Sleep) subscale

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.59	0.06	10.01	205	**<.00005**	0.30
Day	-0.03	0.03	-1.29	205	0.10	
Amber Glasses	-0.01	0.08	-0.13	205	0.45	
Grey Glasses	-0.01	0.08	-0.08	205	0.47	
Washout	-0.92	0.24	-3.75	205	**0.0001**	
Day*Amber Glasses	0.03	0.03	1.07	205	0.14	
Day*Grey Glasses	0.03	0.03	1.11	205	0.13	
Day*Washout	0.13	0.04	3.37	205	**0.0004**	

Table 4.
Paired samples t-test results for outcome variables measured only on Sleep Lab Phases 1 and 2.

	M_1	SD_1	M_2	SD_2	*t*	*df*	*p*	*Cohen's d*
Sleep_duration_WatchPAT	384.27	32.07	359.73	56.00	1.60	14	0.131	-0.56
REM_latency_WatchPAT	91.36	57.02	112.07	59.63	-1.00	13	0.334	0.37
Number_wakes_WatchPAT	6.53	3.81	5.60	2.32	0.81	14	0.433	-0.31
Mean_pulse_WatchPAT	57.00	9.66	57.80	8.98	-0.22	14	0.826	0.09
Oxy_saturation_WatchPAT	95.80	0.94	95.67	1.29	0.30	14	0.769	-0.12
Sleep_duration_PSQI_AM	7.22	0.96	6.98	1.41	0.56	14	0.58	-0.21
PSQI_Sleep_Quality_AM	1.70	0.67	1.80	0.79	-0.26	9	0.798	0.14
PSQI_Sleep_Quality_PM	2.00	0.41	2.08	0.49	-0.56	12	0.585	0.18
Sleep_latency_WatchPAT	31.27	14.65	29.73	15.11	0.26	14	0.800	-0.11
Sleep_latency_PSQI_AM	14.71	8.34	19.14	21.45	-0.70	13	0.494	0.28
Sleep_latency_PSQI_PM	14.67	9.32	25.67	39.78	-0.95	11	0.363	0.40

Note: Groups are indicated by subscripts. Group 1 is the amber glasses active condition, and group 2 is the grey glasses control condition, so positive values of d mean that the average was higher in the amber condition.

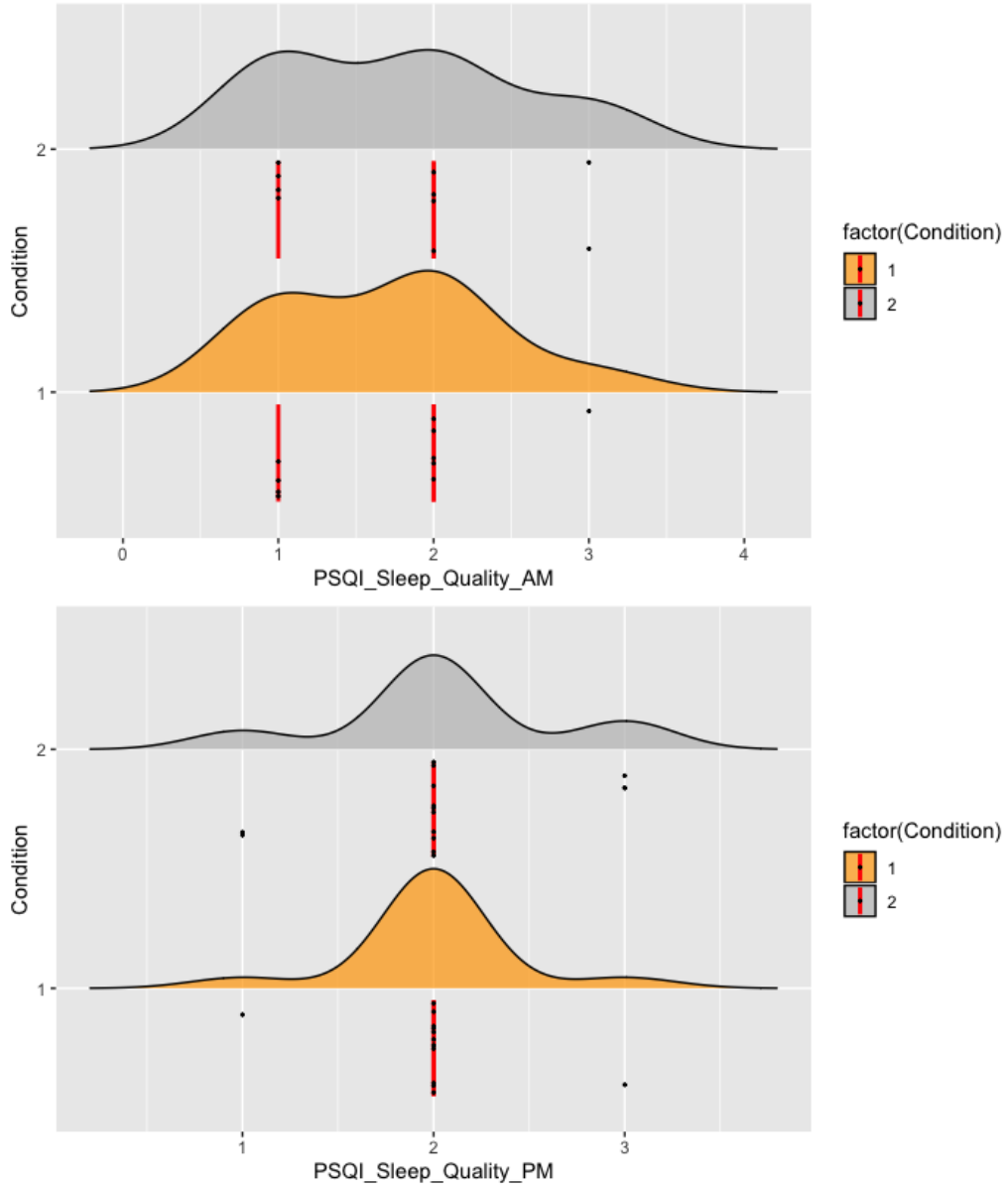

Figure 5. Ridgeline plots of sleep quality measures by condition: PSQI sleep quality item measured in the morning and in the evening. The three red lines on each ridgeline plot indicate—from left to right—the first quartile, the median, and the third quartile. The sleep quality differences between the amber glasses and grey glasses groups were non-significant for both the PSQI_AM and PSQI_PM.

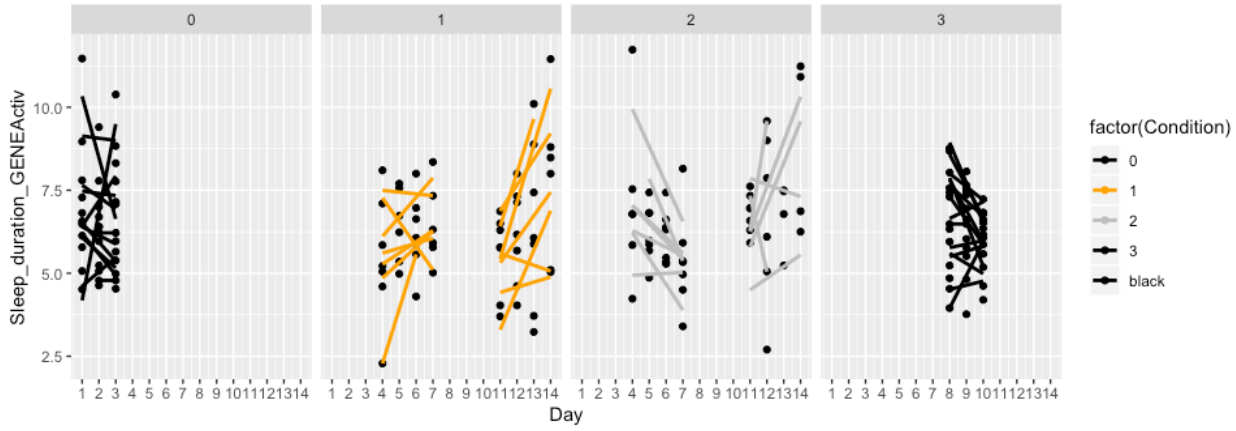

Figure 6. Spaghetti plots for the sleep duration (in hours) outcome measure by condition: GENEActiv. Trend lines are regressions for each participant showing changes in the outcome variable over the days in each condition. Colors represent the glasses conditions, the first panel represents baseline, and the fourth panel represents the washout phase. For GENEActive measurements, sleep duration was filtered so values over 12 hours were excluded, as more extreme values of sleep duration indicate that participants neglected to put on the GENEActiv device. For the GENEActiv sleep duration outcome variable, there was a significant effect of the amber glasses condition, indicating an immediate but non-progressive decrease in sleep duration as a result of the amber glasses intervention.

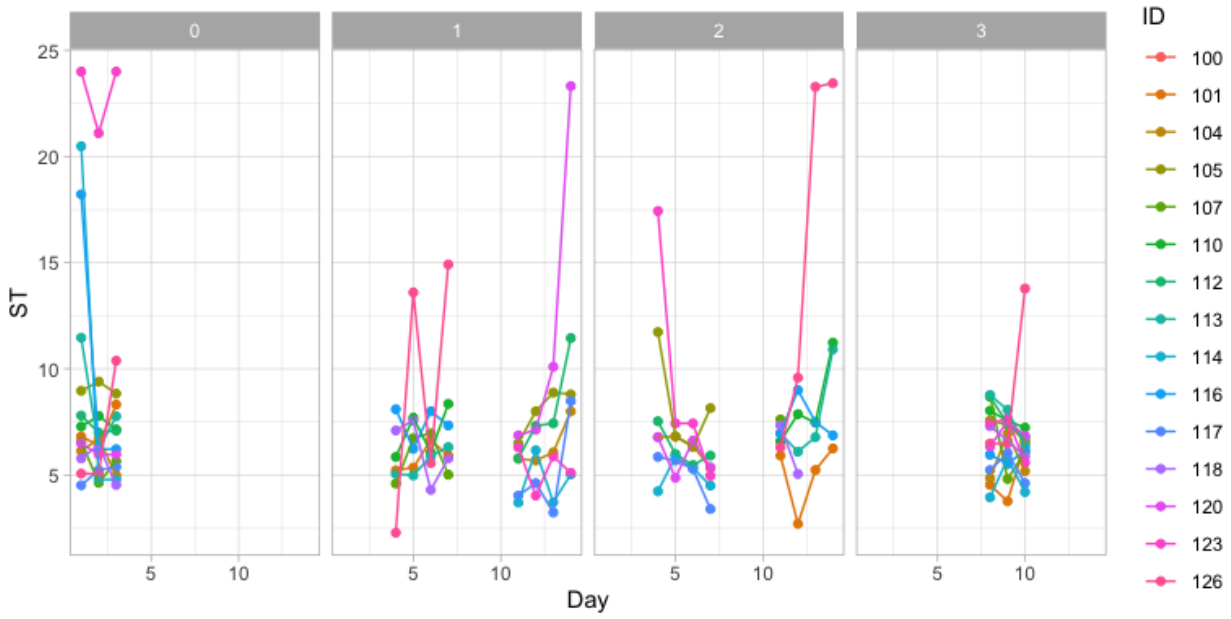

Figure 7. Spaghetti plots for sleep duration (in hours) outcome measure by condition: GENEActiv. Trend lines connect the data points for each participant showing changes in the outcome variable over the days in each condition. Colors represent each participant. Panels 0 through 3 represent the baseline, amber glasses, grey glasses, and washout conditions, respectively. Participants with sleep duration over 12 hours were filtered out before linear mixed effects regression analyses were conducted, as extreme values indicated participants not wearing the GENEActiv device. These participants were, however, kept in this figure for clarity about spread of data.

Table 5.
Beta Weights Predicting Sleep Duration as measured by GENEActiv

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	6.76	.65	10.44	179	**<.00005**	.283
Day	-0.08	0.27	-0.30	179	0.38	
Amber Glasses	-1.76	0.83	-2.13	179	**0.02**	
Grey Glasses	-0.68	0.85	-0.80	179	0.21	
Washout	2.81	2.40	1.17	179	0.12	
Day*Amber Glasses	0.23	0.28	0.80	179	0.21	
Day*Grey Glasses	0.14	0.28	0.51	179	0.31	
Day*Washout	-0.26	0.38	-0.71	179	0.24	

Note: Sleep duration was filtered so values over 12 hours were excluded, as more extreme values of sleep duration indicate that participants neglected to put on the GENEActiv device.

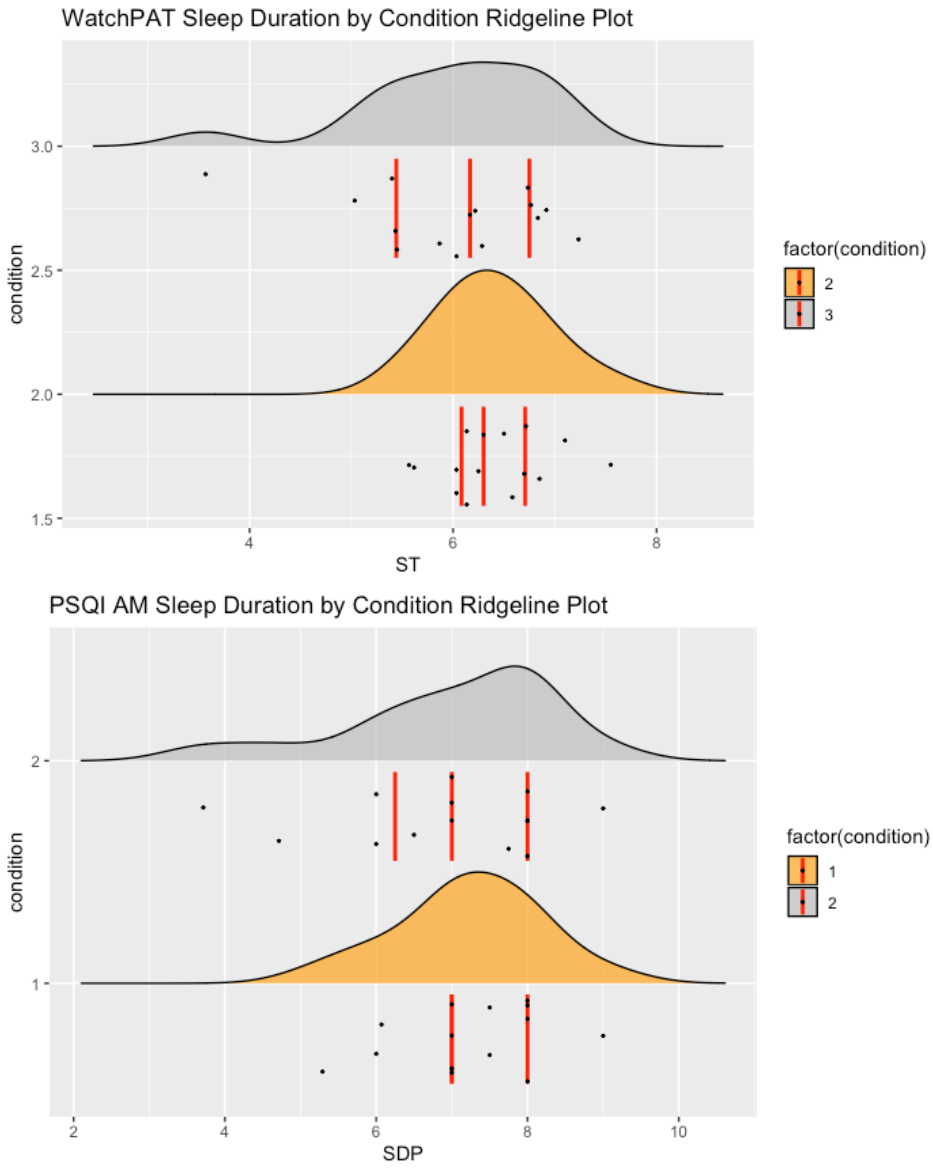

Figure 8. Ridgeline plots of sleep duration (in hours) measured by WatchPAT and PSQI in the morning by condition. The three red lines on each ridgeline plot indicate—from left to right—the first quartile, the median, and the third quartile. The groups differences for sleep duration were approaching significance for the WatchPAT and non-significant for the PSQI_AM.

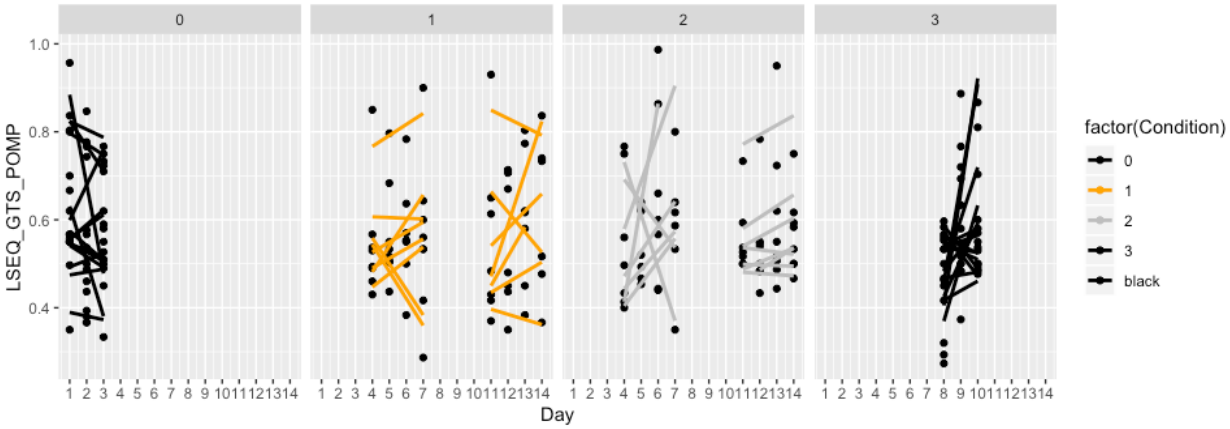

Figure 9. Spaghetti plots for sleep latency outcome variable by condition: LSEQ_GTS (Getting to Sleep). Trend lines are regressions for each participant showing changes in the outcome variable over the days in each condition. Colors represent the glasses conditions, the first panel represents baseline, and the fourth panel represents the washout phase. For LSEQ_GTS, there were significant effects of the washout condition, and the day by washout condition, in that the washout condition caused a significant and immediate decrease in ease of getting to sleep, and but the participants' scores increased back to baseline levels as days in the washout phase passed.

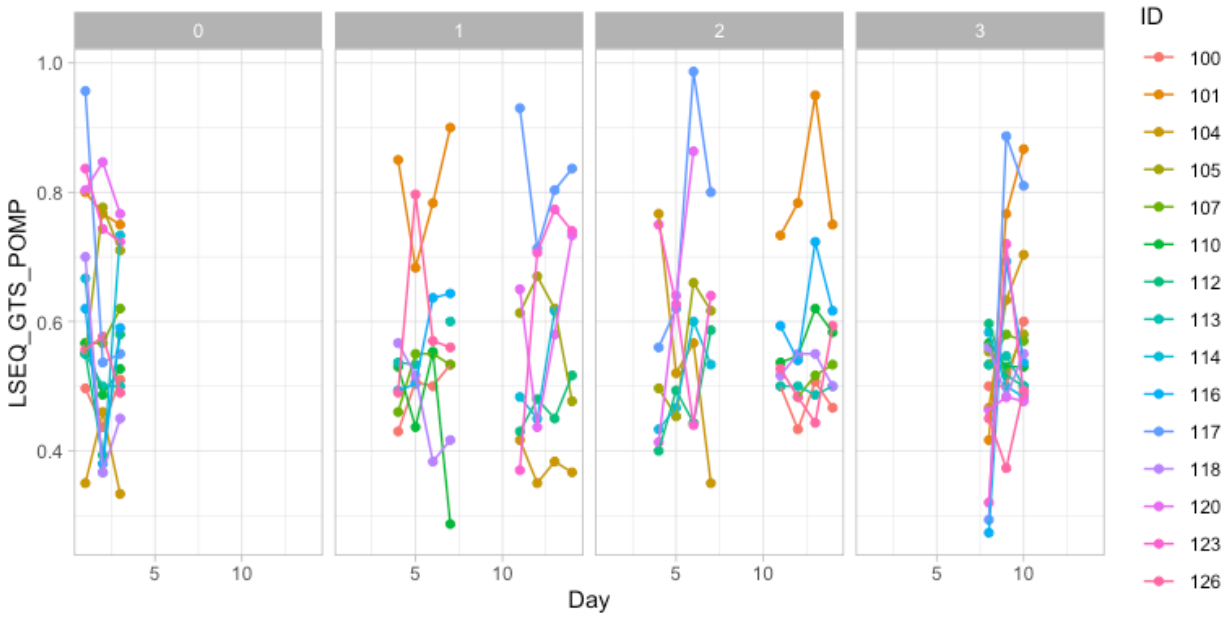

Figure 10. Spaghetti plots for sleep latency outcome variable by condition: LSEQ_GTS (Getting to Sleep). Trend lines connect the data points for each participant showing changes in the outcome variable over the days in each condition. Colors represent each participant. Panels 0 through 3 represent the baseline, amber glasses, grey glasses, and washout conditions, respectively.

Table 6.
Beta Weights Predicting Sleep Quality as measured by the LSEQ GTS (Getting to Sleep) subscale

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.64	0.05	13.27	206	**<.00005**	0.42
Day	-0.02	0.02	-1.22	206	0.11	
Amber Glasses	-0.07	0.06	-1.08	206	0.14	
Grey Glasses	-0.10	0.06	-1.56	206	0.06	
Washout	-0.57	0.18	-3.03	206	**0.001**	
Day*Amber Glasses	0.02	0.02	1.15	206	0.13	
Day*Grey Glasses	0.03	0.02	1.35	206	0.09	
Day*Washout	0.08	0.03	2.70	206	**0.004**	

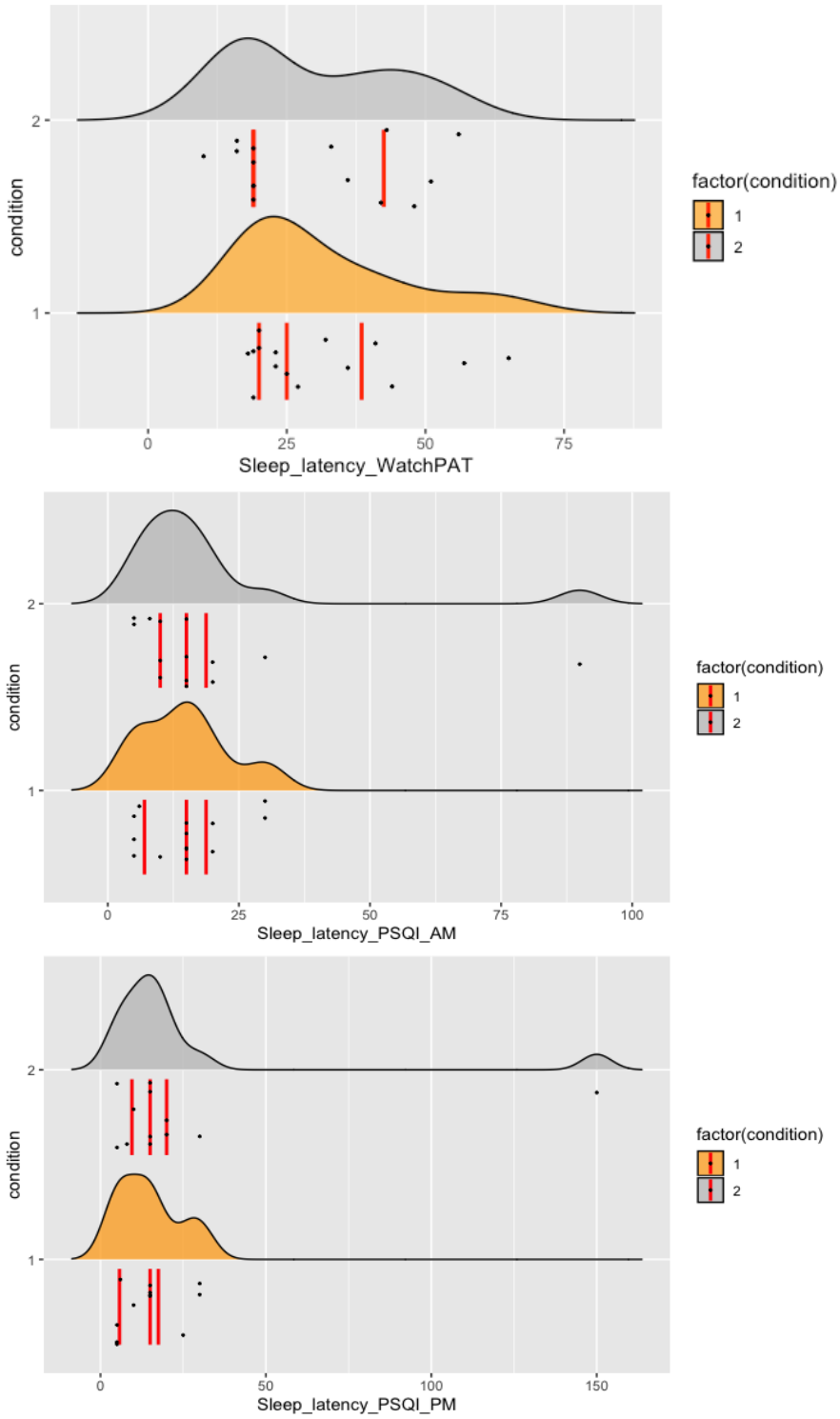

Figure 11. Ridgeline plots of sleep latency measured by WatchPAT, PSQI in morning, PSQI in evening by condition. The three red lines on each ridgeline plot indicate—from left to right—the first quartile, the median, and the third quartile. The groups differences in sleep latency were non-significant for WatchPAT, PSQI_AM, and PSQI_PM. These measurements took place on the same nights of sleep, and from these data, it is apparent that participants generally self-rated their sleep latency lower than what was measured objectively my the WatchPAT.

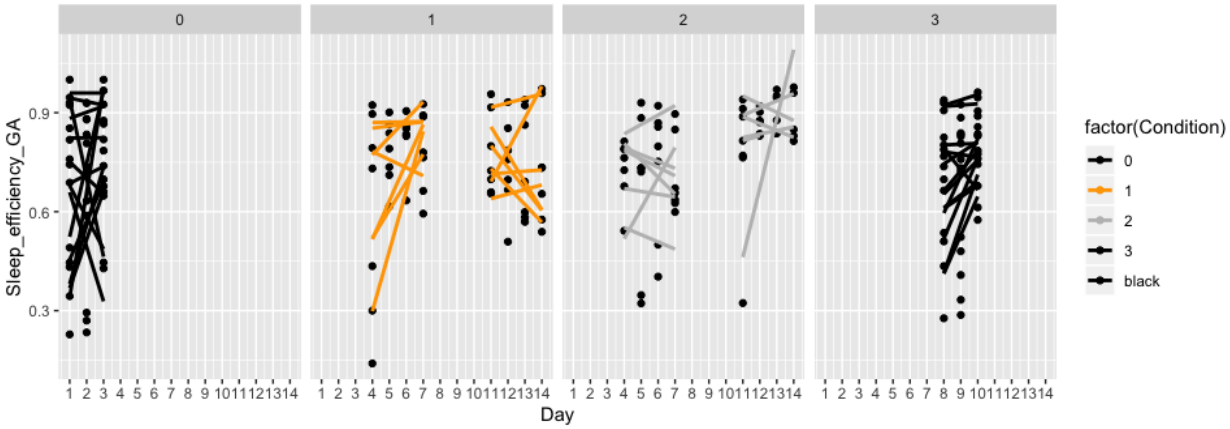

Figure 12. Spaghetti plots for GENEActiv sleep efficiency outcome variable by condition. Trend lines are regressions for each participant showing changes in the outcome variable over the days in each condition. Colors represent the glasses conditions, the first panel represents baseline, and the fourth panel represents the washout phase. For the GENEActiv sleep efficiency outcome variable, there were no significant effects of day, condition, or the day by condition interaction.

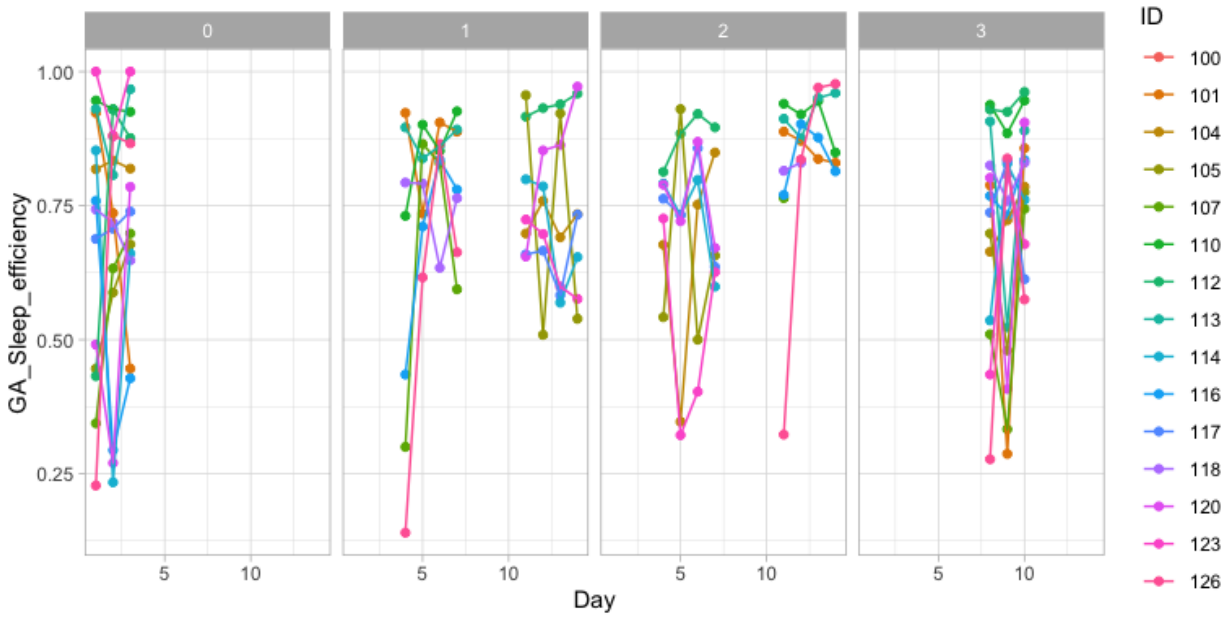

Figure 13. Spaghetti plots for GENEActiv sleep efficiency outcome variable by condition. Trend lines connect the data points for each participant showing changes in the outcome variable over the days in each condition. Colors represent each participant. Panels 0 through 3 represent the baseline, amber glasses, grey glasses, and washout conditions, respectively.

Table 7.
Beta Weights Predicting Sleep Efficiency as measured by GENEActiv

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.64	0.07	9.24	191	**<.00005**	0.162
Day	0.03	0.03	1.09	191	0.14	
Amber Glasses	0.09	0.09	0.93	191	0.18	
Grey Glasses	-0.03	0.09	-0.33	191	0.37	
Washout	-0.35	0.29	-1.22	191	0.11	
Day*Amber Glasses	-0.03	0.03	-0.97	191	0.17	
Day*Grey Glasses	-0.01	0.03	-0.46	191	0.32	
Day*Washout	0.01	0.04	0.34	191	0.37	

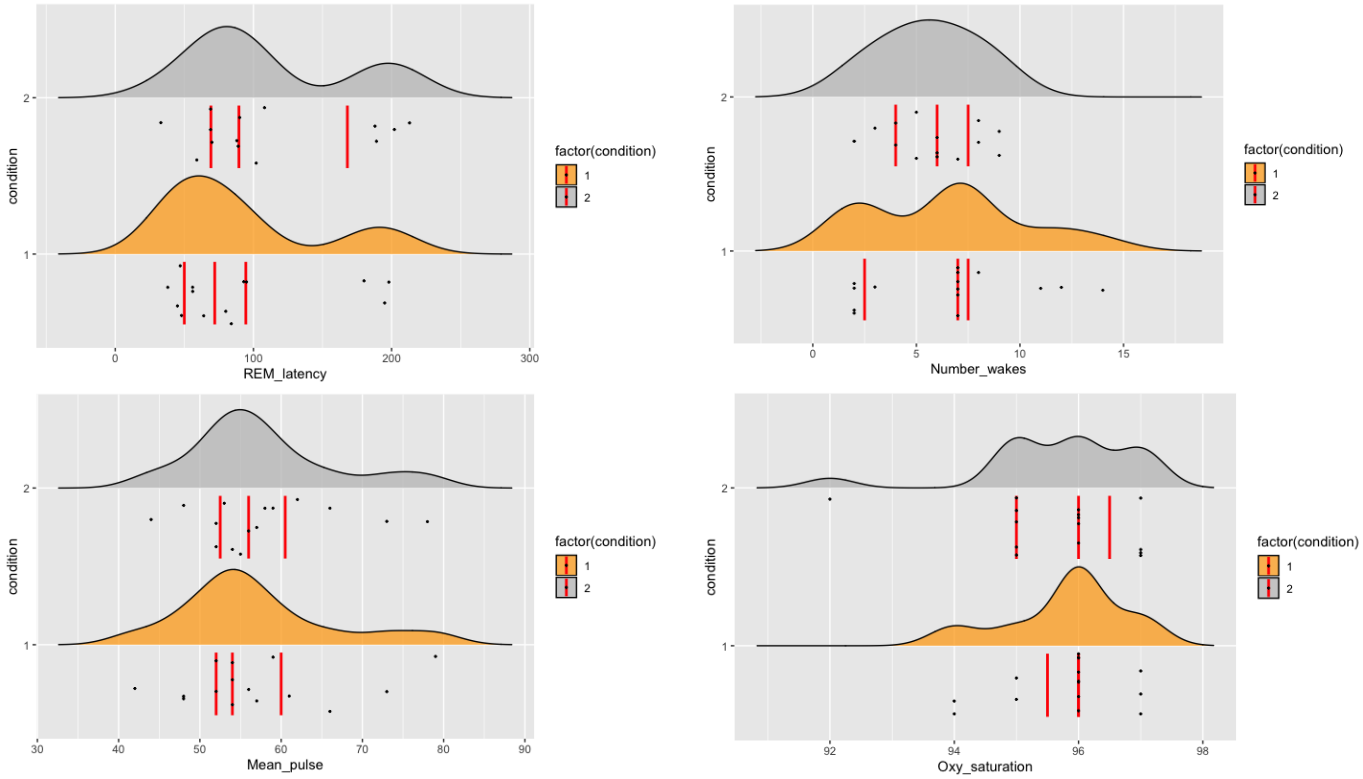

Figure 14. Ridgeline plots of WatchPAT extraneous sleep factors by condition: REM Latency, number of wakes, mean pulse, and mean oxygen saturation measured by WatchPAT by condition. The three red lines on each ridgeline plot indicate—from left to right—the first quartile, the median, and the third quartile. All four of the associated *t*-tests were non-significant.

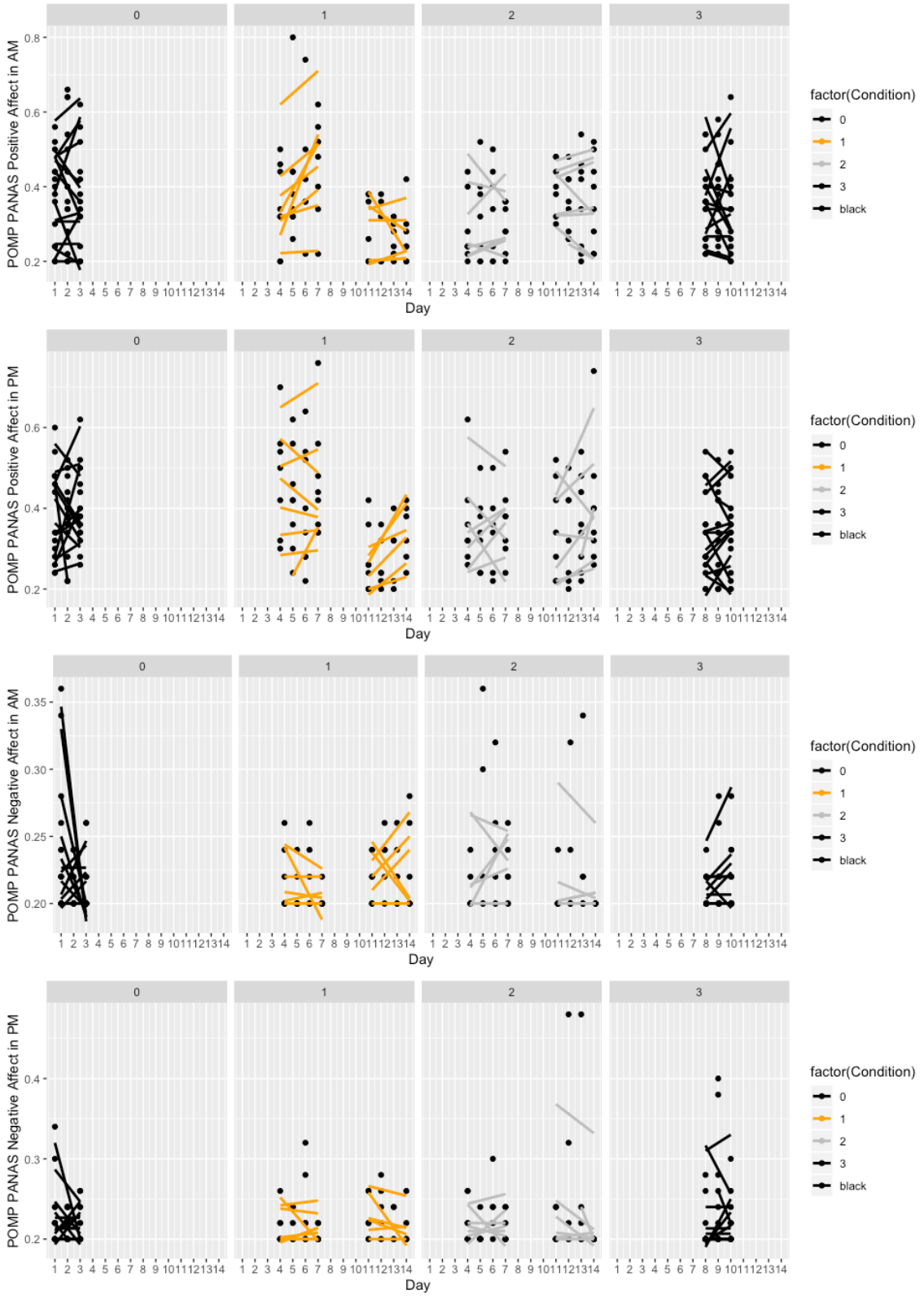

Figure 15. Spaghetti plots for PANAS Positive Affect AM and PM and PANAS Negative Affect AM and PM outcome variables by condition. Trend lines are regressions for each participant showing changes in the outcome variable over the days in each condition. Colors represent the glasses conditions, the first panel represents baseline, and the fourth panel represents the washout phase.

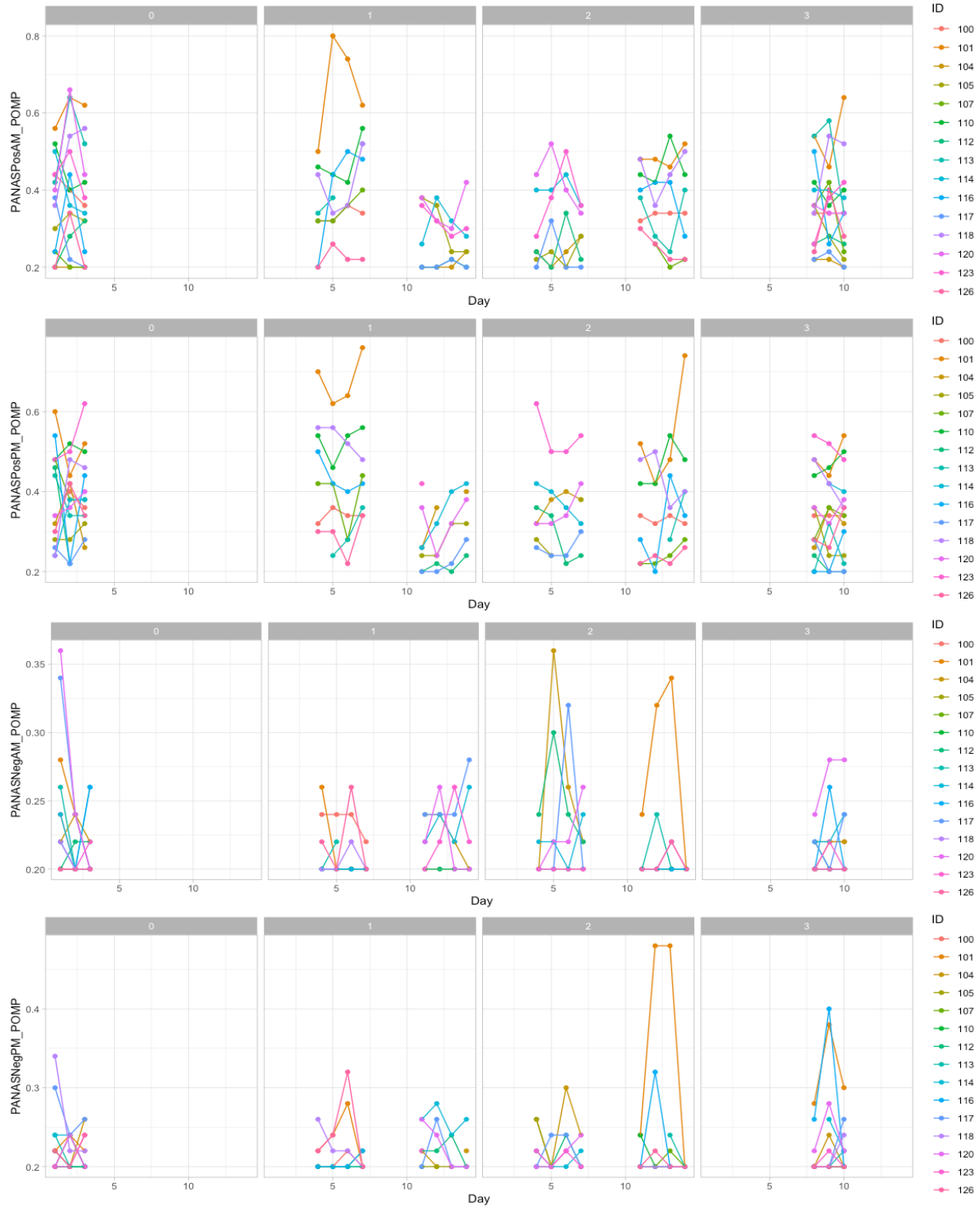

Figure 16. Spaghetti plots for PANAS Positive Affect AM and PM and PANAS Negative Affect AM and PM outcome variables by condition. Trend lines connect the data points for each participant showing changes in the outcome variable over the days in each condition. Panels 0 through 3 represent the baseline, amber glasses, grey glasses, and washout conditions, respectively.

Table 8.
Beta Weights Predicting Positive Affect in AM as measured by PANAS

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.38	0.04	10.10	208	**<.00005**	0.57
Day	-0.00	0.01	-0.20	208	0.42	
Amber Glasses	0.01	0.04	0.32	208	0.37	
Grey Glasses	-0.00	0.04	-0.12	208	0.45	
Washout	0.05	0.12	0.38	208	0.35	
Day*Amber Glasses	-0.00	0.01	-0.20	208	0.42	
Day*Grey Glasses	-0.00	0.01	-0.10	208	0.46	
Day*Washout	-0.00	0.02	-0.28	208	0.39	

Table 9.
Beta Weights Predicting Positive Affect in PM as measured by PANAS

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.38	0.04	10.64	199	**<.00005**	0.57
Day	0.00	0.01	0.19	199	0.42	
Amber Glasses	0.08	0.04	2.03	199	**0.02**	
Grey Glasses	0.02	0.04	0.47	199	0.32	
Washout	-0.07	0.12	-0.61	199	0.27	
Day*Amber Glasses	-0.01	0.01	-0.87	199	0.19	
Day*Grey Glasses	-0.01	0.01	-0.52	199	0.30	
Day*Washout	0.00	0.02	0.06	199	0.48	

Table 10.
Beta Weights Predicting Negative Affect in AM as measured by PANAS

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.25	0.01	22.86	208	**<.00005**	0.33
Day	-0.01	0.00	-2.79	208	**0.003**	
Amber Glasses	-0.03	0.01	-2.27	208	**0.01**	
Grey Glasses	-0.02	0.01	-1.65	208	**0.05**	
Washout	-0.06	0.04	-1.34	208	0.09	
Day*Amber Glasses	0.01	0.00	2.74	208	**0.003**	
Day*Grey Glasses	0.01	0.00	2.62	208	**0.005**	
Day*Washout	0.02	0.01	2.37	208	**0.009**	

Table 11.
Beta Weights Predicting Negative Affect in PM as measured by the PANAS

Predictor	*ß*	$SE_{ß}$	*t*	*df*	*p*	*ICC*
(Intercept)	0.23	0.02	14.64	199	**<.00005**	0.32
Day	-0.00	0.01	-0.79	199	0.22	
Amber Glasses	-0.02	0.02	-0.93	199	0.18	
Grey Glasses	-0.01	0.02	-0.61	199	0.27	
Washout	-0.03	0.06	-0.45	199	0.33	
Day*Amber Glasses	0.01	0.01	0.88	199	0.19	
Day*Grey Glasses	0.01	0.01	0.86	199	0.20	
Day*Washout	0.01	0.01	0.80	199	0.21	

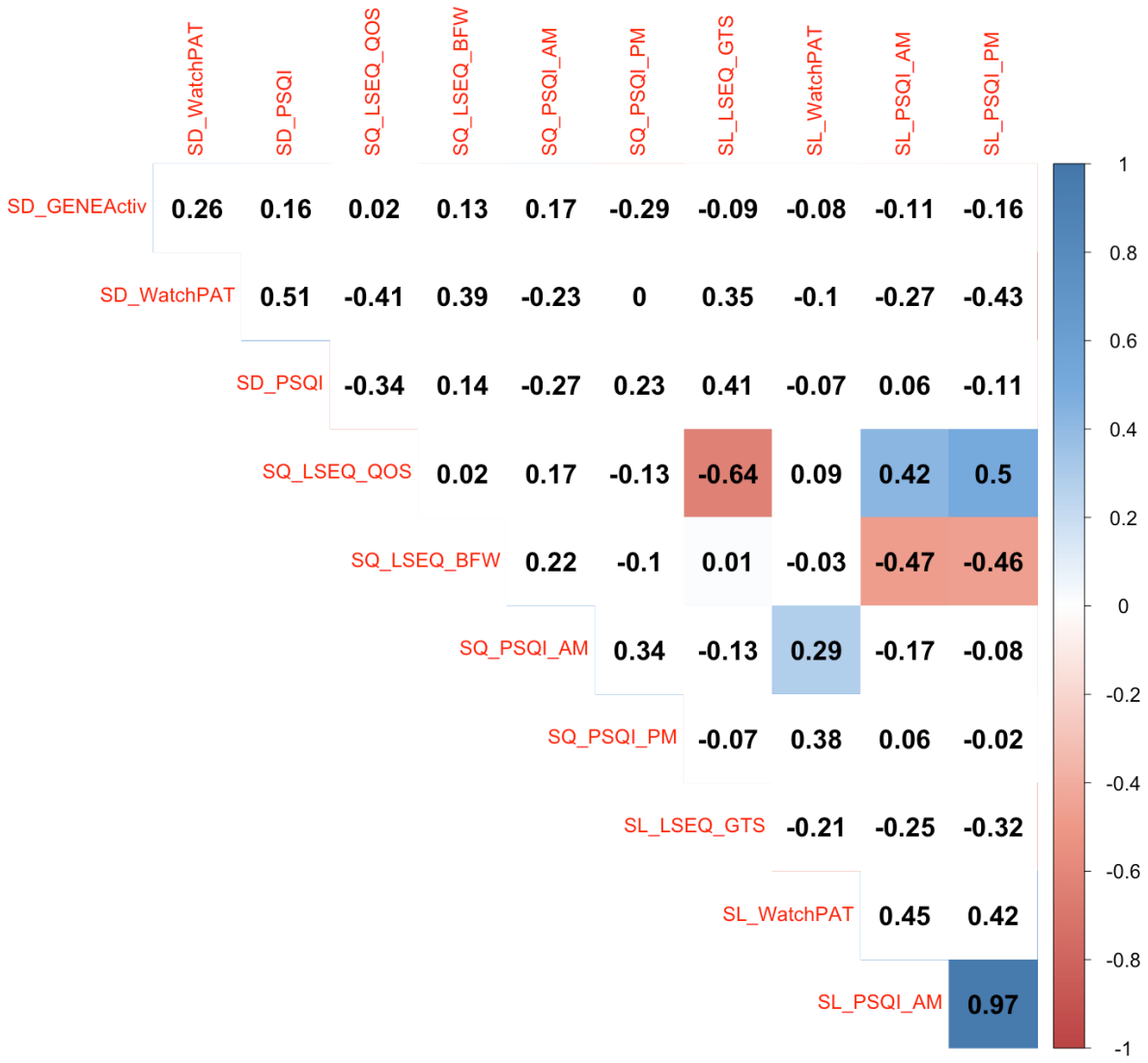

Figure 17. Pearson correlation matrix representing the agreement between multiple sleep duration (SD), sleep quality (SQ), and sleep latency (SL) measures. Significant correlations are filled-in and insignificant correlations are blank.